ELECTRONIC DESIGN • DEVELOPMENT • MANUFACTURING

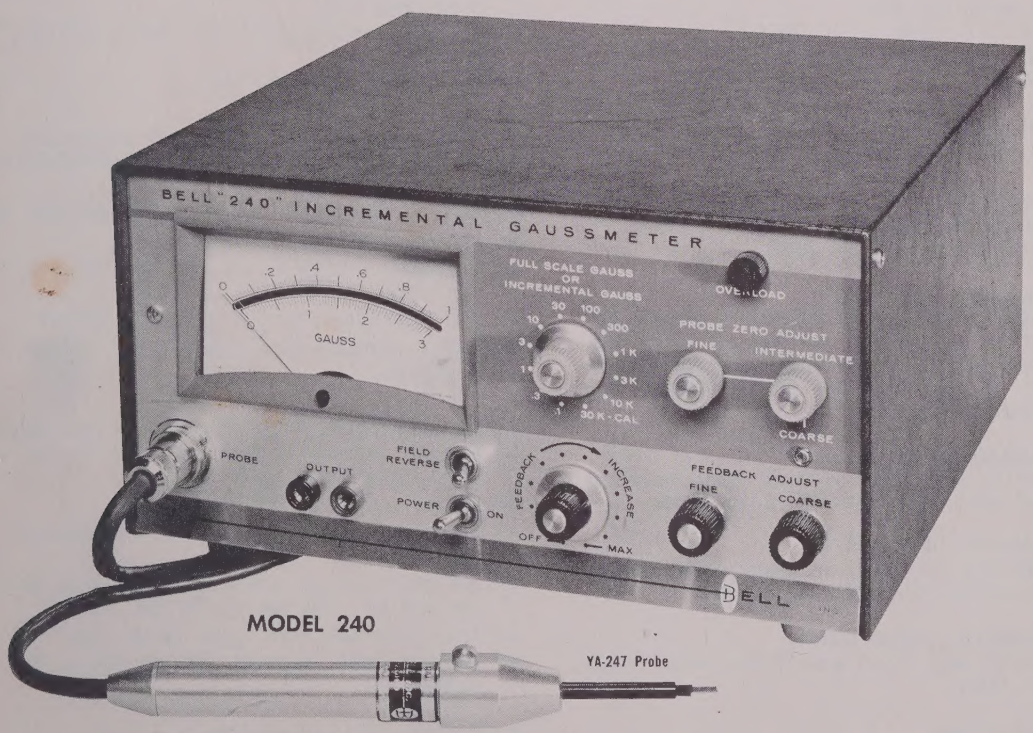
BELL INC.
COLUMBUS, OHIO

Operating and Servicing Manual

MODEL 240

GAUSSMETER

PROBE STE 7-0204 JUNE 75



MODEL 240

YA-247 Probe

BELL INC.
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SECTION I

Specifications Model 240 Gaussmeter

RANGES
12 ranges in gauss, full scale

.1	3	100	3K
.3	10	300	10K
1.	30	1K	30K

INSTRUMENT ACCURACY
± 1% of full scale to 10KG.

PROBE LINEARITY
± 1% of absolute field to 10KG;
Refer to calibration data above 10KG.

B MEASUREMENT ACCURACY
Over-all measurement accuracy affected by instrument accuracy and probe linearity, and depends upon calibration method used. 1/2% calibration magnets available from F. W. Bell, Inc. See Section III-7 on Accuracy of Measurement.

ΔB MEASUREMENT ACCURACY
1% to 5% of full scale value of range used, depending on amount of scale expansion and ranges used.

B MEASUREMENT RESOLUTION
1 part in 100 (1% of full scale, using panel meter), improved resolution using external readout.

ΔB INCREMENTAL RESOLUTION
1 part in 10,000 (max.) of full scale measurement range, 10G to about 14KG.

SCALE EXPANSION
100 times

ZERO SUPPRESSION
To approx. 14KG.

OUTPUT JACKS (front panel)
(a) Voltage –2 volts d-c ± 10% for a full scale signal.
(b) Source resistance, 50K ohms.
(c) Frequency response, zero to 60 cps. See response curve, Fig. III-3.
(d) A-C field output is 0.5 volt rms at 60 cps, maximum.
(e) Noise residuals, 10 mv rms.

IF YA-478 400 CYCLE FILTER IS SUPPLIED, THE FOLLOWING OUTPUT JACKS SPECIFICATIONS APPLY:
(a) Voltage, 300 mv d-c ± 10% for a full scale signal.
(b) Source resistance 10K ohms.
(c) Frequency response, zero to 400 cps, see curve, Fig. III-3.
(d) A-C field output 150 mv rms up to 400 cps.
(e) Noise residuals, zero signal 3 mv, carrier ripple negligible.

AUXILIARY AMPLIFIER TERMINALS (on rear panel)
(a) Voltage, adjustable from –2 volts d-c for a full scale signal to –5 volts d-c.
(b) Source resistance 150 ohms.
(c) Frequency response 0-250 cps. See response curve Fig. III-3.
(d) A-C fields output is 3.5 volts rms up to about 250 cps and 2.5 volts rms at 400 cps.
(e) Noise residuals, zero signal, 65 mv rms.
(f) Carrier ripple residual 250 mv for a full scale signal.

POWER INPUT REQUIREMENTS
117/234 volts rms ± 10% 50-60 cycles, 50 watts.

DIMENSIONS
12″ wide, 14-1/2″ deep, over-all height 7″.

WEIGHT
Net 20 lbs., shipping 24 lbs.

BELL MODEL 240 GAUSSMETER

MANUAL CHANGES

Please note the following changes:

1) ZERO CONTROLS

   a. A "ZERO CONTROL OUT" switch has been added to accomodate special accessories such as the Differential and High Field Probes. This switch is operated by rotating the "INTERMEDIATE" Zero control fully counterclockwise until an audible click is heard. In this position, the internal gaussmeter zero controls are disabled. WHEN USING PROBES THAT DO NOT HAVE THEIR OWN ZERO CONTROLS (SUCH AS YA-247 AND YA-248 STANDARD PROBES), BE SURE THAT THE INTERMEDIATE ZERO CONTROL IS NOT IN THE EXTREME COUNTER-CLOCKWISE POSITION.

SECTION II
General Description

II-1 GENERAL

The Model 240 Incremental Gaussmeter is a precision magnetic field measuring instrument having outstanding capabilities for: (a) direct-reading flux density measurement, (b) expanded scale incremental flux density measurements, with high sensitivity to small changes in field density and direct reading of such incremental changes.

The Model 240 has been designed specifically for use with the Hall-effect, magnetic field probes manufactured by F. W. Bell, Inc. using Bell Hall-Pak sensing elements. A wide variety of probe configurations is available, and probes can be interchanged in the Model 240 using a simple recalibration procedure.

Simplicity of operation is achieved without sacrificing accuracy, sensitivity or flexibility of application. Measurement range extends from 1 milligauss per scale division (100 mg full scale) to 30,000 gauss full scale. Static or d-c magnetic fields are indicated directly on the panel meter to 10,000 gauss and with reduced accuracy to 30,000 gauss. On later units, calibration test points are provided in the range of 10 kg to 30 kg.

Output terminals are provided on the gaussmeter. A d-c or a-c voltage appears at these terminals which is accurately calibrated to the value of static or alternating magnetic field being measured. The field direction, or d-c field polarity information, is not lost in the measurement. Alternating fields up to 400 cycles may be observed and measured using an external instrument (VTVM or oscilloscope). An auxiliary output amplifier provides adjustable and proportional output voltage with sufficient volt-ampere capacity to operate sensitive relays or other external control equipment directly. This feature makes the Model 240 particularly suitable for industrial test, inspection and control applications.

II-2 CONTROLS AND CONNECTORS

A. FRONT PANEL

Power

This toggle switch turns on the primary power to the unit.

Field Reverse

This toggle switch provides for an up-scale reading when the field direction is reversed.

Range Switch

This switch is marked FULL SCALE GAUSS or INCREMENTAL GAUSS. Its purpose is to select the full scale meter range in gauss when the instrument is used as a direct reading gaussmeter. When used as an incremental instrument, the switch position indicates the full-scale range of the Δ gauss increment, or change in magnetic field strength.

Probe Zero Adjustments (Gray Knobs)

The controls marked INTERMEDIATE and FINE and the screw-driver slot COARSE adjustments are used to balance each individual probe which is connected to the instrument.

Feedback Controls (Black Knobs)

The FEEDBACK-INCREASE switch and the two controls marked COARSE and FINE are used to vary the amount of feedback voltage, which makes it possible to measure incremental field changes.

Output Jacks

The BLACK-RED front panel jacks will accept a standard double banana plug with ¾" spacing. They provide an output voltage which is accurately proportional to the value of flux density being measured, relative to the full-scale range in use. The left-hand jack (black) is connected to chassis. The red jack will deliver 2 volts (negative to ground) for a full scale reading on the meter. Source impedance is 50,000 ohms and response is to 60 cps using the standard filter provided.

If the Model 240 is provided with a 400 cycle filter, response is extended to 400 cycles; at reduced output voltage.

B. REAR PANEL

Control Current

The level switch (S3) and slotted shaft control (R9) are used to read and adjust the probe control current. With S3 in the up position, the front panel meter reads control current milliamperes.

Cal

Lever switch (S4) and slotted shaft control (R52) are used for probe calibration. With S4 in the up position, R52 will calibrate the amplifier gain for the particular probe in use.

Detector Bal

This is a factory adjustment which is used to zero the meter under zero signal conditions. Do not disturb this adjustment.

Auxiliary Output Zero

This control is adjusted for zero voltage at the AUX OUTPUT terminals under zero signal conditions.

Auxiliary Output Cal

This control adjusts the voltage at the AUX OUTPUT terminals from –2 to –5 volts full-scale. This is to permit optimum matching to external load requirements.

Relay Bias

This is a factory adjustment and sets the trigger point for the overload light relay. Do not disturb this adjustment.

Aux Output

These terminals on the rear panel provide an accurately field-proportional output voltage relative to the full scale range in use. The signal is suitable for driving external equipment for measurement, recording or control purposes. It is isolated from the front-panel output jacks except for common chassis ground.

Meter

These terminals provide means for externally short-circuiting the panel meter when the instrument is used as a differential gaussmeter.

II-3 POWER

The power cable supplied has three conductors and is terminated in a three-prong plug recommended by the National Electrical Manufacturers' Association. The round pin is connected to the chassis and grounds the instrument case and output terminals when used with the appropriate receptacle. An adapter may be used for connection to a standard two-contact receptacle. The ground is brought out of the adapter by means of a short wire which should be connected to a suitable ground for protection of operating personnel. Only when a ground is supplied by associated equipment should this ground be unused to prevent common ground currents.

The Model 240 is normally wired for operation from a 117 volt, 50-60 cps power source. To convert it for 234 volt 50-60 cps operation the dual primary of the power transformer is changed from parallel to series connection. Refer to the schematic diagram for details. When converting from 117 volt to 234 volt operation, replace the 1 ampere slow-blow fuse with a ½ ampere slow-blow fuse.

SECTION III
Operating Instructions

III-1 PROBE HANDLING

CAUTION

The sensing elements used in the YA-247 probes are exteremely thin and fragile and can easily be permanently damaged. Special care should be exercised in handling the transverse probe, YA-247, which allows exposure of the thin sensing element for measurements in narrow gaps. To expose the element, rotate the outer protective tube counter-clockwise (about 30 degrees). This releases the safety catch and allows the tube to be pushed back into the handle. Always restore the outer tube to the protective position when not actually making narrow gap measurements. The safety catch will automatically engage when the tube is pulled out to its extreme position and released. Axial probes, such as the YA-248, are not as fragile as the transverse probes and have no protective tube.

The sensing element used in all probes is strain sensitive and no forces should be applied directly against it during measurement. Also, it should be protected from temperature shock, such as touching against hot or cold objects. High temperature environments, rapid thermal changes, or high velocity air flow over the element can also result in apparent drift of the zero setting on the lower ranges and should be avoided.

No attempt should be made by the user to repair or modify the probe assembly in any way. The probe cable is of special design and its terminations in the cable plug and probe handle are very precisely adjusted to cancel out quadrature voltages which would cause overload and nonlinear operation on the lower ranges. Probes with special cable lengths can be supplied on special order.

III-2 APPLYING POWER

Before turning the instrument on, make certain the power available matches the voltage and frequency rating of the gaussmeter. Connect a probe to the input receptacle. It is important that the plug is pushed firmly into the panel socket until fully seated, then screw in the clamp ring until it is snug. Turn the RANGE SWITCH to the 30K position, and the FEEDBACK SWITCH to the OFF position. Determine whether the 3-prong to 2-prong line cord adapter should be used (see paragraph on POWER sec. II-3). Plug in the power plug and turn the POWER SWITCH on. Allow 5 minutes for preliminary warm-up. Complete stability is reached in about one hour.

III-3 PROBE BALANCE ADJUSTMENTS

These are "nulling" adjustments wherein the meter reading is brought to zero with zero field at the Hall probe.

A. COARSE ZERO ADJUSTMENT

If the instrument has not been previously adjusted for the particular probe installed, some adjustment of the coarse trimmer will probably be required. First set the INTERMEDIATE control to approximately mid-range. Rotate the RANGE selector counter-clockwise until a reading is obtained on the meter (if down-scale reading occurs, throw REVERSE switch to opposite position). Adjust trimmer to reduce reading toward zero while continually reducing the range setting until near zero reading is obtained on the 30 gauss range. Do not adjust COARSE potentiometer on lower ranges. Notice that the COARSE trimmer changes occur in "steps". Make certain final adjustment is made by carefully setting on the "plateau" between steps. Avoid setting near the edge of a step as such a setting may prove to be unstable.

B. INTERMEDIATE AND FINE ZERO ADJUSTMENTS

The INTERMEDIATE CONTROL will now have adequate range to provide adjustment to zero and about one gauss or more each side of zero. For precise zeroing on the lower ranges use the FINE control as needed. The probe must be shielded from the earth's field to obtain a true zero. The use of a zero gauss chamber is recommended. The above zeroing procedure can be carried out quite rapidly without "banging" the meter pointer in the process. Although meter protection is designed into the circuitry, needless "banging" of the pointer can result in meter damage and should be avoided.

NOTE: It is important to note that this instrument has high sensitivity and that the earth's magnetic field will read off-scale on the low ranges.

III-4 CALIBRATION PROCEDURE

The calibration procedure should be carried out before using the instrument for magnetic field measurements. It must also be carried out whenever probes are changed. Allow sufficient time for the instrument to reach stability before calibrating. Probes require about 10 minutes after plugging into a hot instrument to stabilize. The probe balancing adjustments described above must first be carried out.

There are two steps involved in calibrating the Model 240.

A—Adjust control current
B—Adjust amplifier gain

A. ADJUST CONTROL CURRENT

After connecting and zeroing the probe, set the rear panel lever switch S3 in the CONTROL CURRENT ADJUST position. Loosen the lock nut on R9 (adjacent to S3) and adjust for exactly full scale deflection on meter. Tighten lock nut and restore S3 to normal position.

B. ADJUST AMPLIFIER GAIN

After setting the control current the amplifier gain must be adjusted in accordance with the sensitivity of the particular probe in use, using one of the following methods:

1. Calibration against a reference magnet.
2. Calibration against probe CAL constant.

For highest accuracy, the use of a calibration magnet is recommended. Calibration against the probe CAL constant is a transfer method giving reduced accuracy. It should be used only when a reference magnet, or accurately known field, is not available. See section III-7 on ACCURACY.

1. CALIBRATION AGAINST A REFERENCE MAGNET

The zero procedure must first be accomplished with the probe inside a shielded chamber, such as the Bell YA-111 zero gauss chamber. Next, set the RANGE switch to proper position for the flux density rating of the reference magnet. Insert the probe in the magnet and position for maximum meter reading. Then adjust the CAL control, R52 on the rear panel, to make the meter reading agree with the value of the reference magnet. The use of a probe holding fixture

is recommended for proper stability of field measurement.

2. CALIBRATION AGAINST PROBE CAL CONSTANT
Each probe has been factory checked against calibrated magnets under standard test conditions and assigned a sensitivity constant, called the CAL CONSTANT. To transfer this value into the instrument, first set the RANGE switch to the 30K-CAL position. Next operate the CAL switch S4 on the rear panel and note the meter reading on the 0-1 scale. Adjust the CAL potentiometer R52 to make the meter read the value of the CAL CONSTANT indicated on the probe handle name plate. Return S4 to normal and the instrument is ready for use.

NOTE: When the Model 240 has been calibrated on one range switch position, the calibration accuracy on other ranges is within the limits of the ¼% precision resistors used in the range switch attenuator.

III-5 MAKING ABSOLUTE FIELD MEASUREMENTS

A. THE PROBE

Various types and sizes of probes are available for use with the Model 240 Gaussmeter. They are characterized primarily by the field direction to which the probe is responsive. Since the Hall output is dependent only on the component of field strength at right angles to the Hall active surface, positioning of the element in the probe provides for various responses such as transverse, axial, tangential, etc. In every case, for determination of absolute value, it is necessary to exactly align the probe so that the Hall element is perpendicular to the field vector.

Since Hall-Pak sensing elements have very small active sensing areas, they sample only a small amount of the field, thus providing good resolution of field gradients. Also, because of small size and non-inductive design, they have negligable effect on the field being measured.

Please note that the FEEDBACK switch must be in the **OFF position** for all absolute measurements.

B. LOW LEVEL MEASUREMENTS

Important

The Model 240 is an extremely sensitive instrument and its use on the lower ranges requires that certain precautions be observed.

The earth's magnetic field will give about half-scale meter reading on the 1 gauss range in the U. S. A. (depending on the position of the sensing element and the setting of the ZERO controls). This can obviously cause increasingly greater errors below the 100 gauss range as well as considerable overload of the instrument on the .3 and .1 gauss ranges. For this reason, the effects of the earth's field (or any other fields that may be present) must be eliminated to obtain satisfactory readings at low levels.

To obtain "absolute" or "true" zero requires adequate shielding of the probe. Shielding can be accomplished by the use of high-permeability material such as mu-metal. The YA-111 ZERO GAUSS CHAMBER provides more than 80 db of attenuation in fields up to 300 gauss. This is more than adequate to reduce the earth's field below the sensitivity of the Model 240 Gaussmeter.

An approximate zero adjustment can be obtained, in the absence of a zero gauss chamber, by the method of orienting the probe in the ambient field so as to obtain both upscale and downscale readings. The zero controls are then adjusted to obtain equal upscale and downscale peak readings.

For many low-level measurements it will not be necessary to obtain "absolute" zero but will be sufficient to reduce the effects of the earth's field and any other constant extraneous fields by one of the following methods:

1. Maintain the probe in a fixed relationship to extraneous fields and use the ZERO controls to "cancel out" their effect.
2. Orient the probe to a point midway between peak readings in each direction.
3. Use Helmholtz coils to generate a cancelling field.

For exploratory work at low flux densities, it is usually satisfactory to mount and clamp the probe in a fixed position, zero out extraneous fields using the zero controls, and then move the device under test in the vicinity of the sensing element.

It is normal to observe a slight zero shift (one or two scale divisions) when the REVERSE switch is operated on the .1 gauss range. This is caused by stray noise residuals in the instrument.

C. PLOTTING FIELD DIRECTION

The YA-247 probes and other similar transverse types are marked to indicate the direction of the flux vector, relative to the probe, for an upscale meter reading on the gaussmeter (when the field direction switch is in the NORMAL position). This is done by providing a red dot or button on the probe. When this marker is oriented toward the NORTH pole of a magnet, the meter will indicate upscale. All F. W. Bell, Inc. calibration magnets are designed to have the NORTH pole above the element when the magnet is upright. In the earth's field, the probe orientation will indicate that the NORTH magnetic pole is in the direction of the south geographic pole.

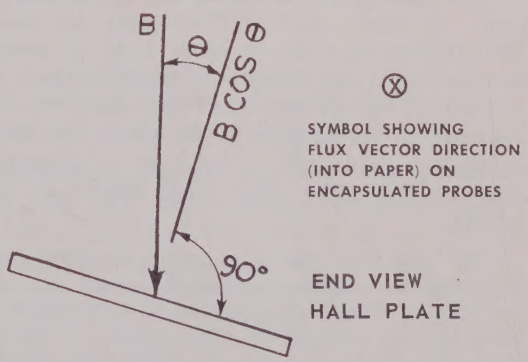


Fig. III-1. Field Relations At Hall Probe

The directional properties of the Hall-effect device can be used to advantage to obtain accurate field direction information. Hall voltage varies as cos θ where θ is the angle of the field vector relative to a normal to the Hall plate. It is therefore a maximum when the field vector is normal to the Hall surface and goes thru a minimum, or null, 90° to the normal. See Fig. III-1.

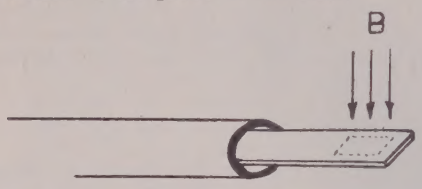
To take advantage of this null, rotate the probe 90° from the maximum output position and orient for zero output. Greatly increased null sensitivity can be obtained by switching to lower gauss ranges. Field direction is then parallel to the sensing element surface.

D. MEASURING D-C FIELDS

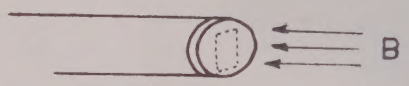
In measuring steady, d-c field magnitude, the probe is oriented in the field or gap to obtain the highest meter reading. For best accuracy always select the range which gives the highest meter deflection.

Transverse probes measure the component of flux density, B, which is normal to the plane of the sensing element. Axial probes measure the component of B which is parallel to the axis of the probe. Careful

positioning of the probe relative to the flux lines is necessary in order to obtain the most accurate reading. If a down-scale reading is obtained, either throw the REVERSE switch on the Model 240 or reverse the position of the probe in the field.



TRANSVERSE PROBE



AXIAL PROBE

Fig. III-2. Basic Probe Configurations.

E. READOUT OF D-C FIELDS

When the probe is oriented for a maximum meter deflection, the absolute value of the field is indicated on the panel meter in gauss. The position of the range switch indicates the full-scale value of meter reading in gauss or kilogauss (KG).

For convenience in reading out on external equipment, the front panel OUTPUT jacks are provided. The voltage appearing at these jacks is accurately proportional to the gaussmeter amplifier signal level, and is a d-c voltage for a static (d-c) field. The source resistance of the jacks is 50,000 ohms. The red jack is negative (–2.0 v dc ±10%) for a full-scale, upscale reading. The other jack (black) is chassis ground.

In addition, the AUXILIARY . AMPLIFIER, a transistor d-c amplifier mounted on the rear panel, provides amplified output at the AUX OUTPUT terminals on the rear panel. This output is adjustable from –2 v d-c to –5 v d-c for a full scale meter deflection and is accurately proportional to flux signal level relative to the range in use. The low output source resistance (150 ohms) permits delivery of 33 ma d-c into a load, at maximum gain.

Highest accuracy is obtained when the AUX gain is adjusted for minimum gain (max. CCW) position. Since the AUX output zero level shifts slightly with the setting of the AUX gain, it should be zeroed when the proper gain setting has been determined.

F. MEASURING A-C FIELDS

Time varying or alternating magnetic fields may be observed and measured on the Model 240, by connecting external instruments such as a recorder or oscilloscope to front panel output jacks or AUX output terminals on the rear. Since the gaussmeter operates on the basis of a field modulated carrier amplifier system, there is a limitation on the maximum frequency that can be observed without interference with the 1.1 KC carrier signal. The relative response of the output jacks and AUX outputs, with field frequency, is given in Fig. III-3. The signal at the front panel output jacks is flat from zero to above 10 cps. It is usable at 60 cps with only 5 mv of residual carrier ripple in the output.

G. READOUT OF A-C SIGNALS

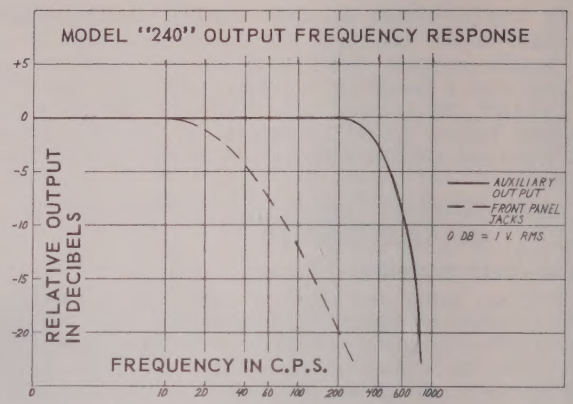


Fig. III-3a. Output Frequency Response.

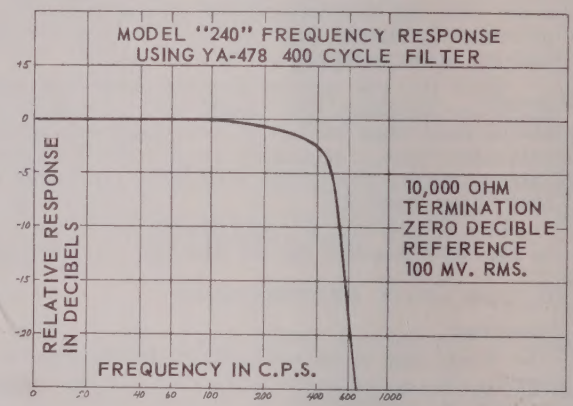


Fig. III-3b. Frequency Response Using YA-478 400 Cycle Filter.

The AUX OUTPUT terminals provide a usable flux-output response up to about 400 cps. A Model 240 equipped with the YA-478 400 cycle filter is recommended for best results to 400 cps, ripple-free. For best response from the AUX OUTPUT terminals, the AUX CAL control should be set for minimum gain, full counterclockwise.

An oscilloscope with d-c response can be quickly calibrated to measure a-c fields directly. An oscilloscope graticule with ten major vertical divisions is very helpful. The oscilloscope is calibrated as follows:

1. Connect the Model 240 output jacks on the front panel to the oscilloscope vertical d-c input.
2. Zero the Model 240 on the 1 gauss range and center the oscilloscope trace on the screen.
3. Adjust the zero controls for full scale meter reading, and the oscilloscope gain to move the trace to the bottom graticule line.
4. Recheck the zero and full scale settings described in 2. and 3. above. The oscilloscope is now calibrated so that full beam deflection corresponds to the full scale value of flux density. This calibration applies to any range on the gaussmeter.
5. Set rear panel switch S3 in the CONTROL CURRENT ADJUST position. This removes the meter from the output circuit to prevent it from influencing response and from unnecessary meter pointer vibration caused by low frequency signals.

When reading a-c fields the steady field (d-c) component should be minimized in order to avoid

amplifier overload. This will be accomplished if the oscilloscope trace is kept in view by adjusting the Model 240 ZERO controls or by probe positioning and NOT by adjusting oscilloscope positioning controls.

NOTE: Maximum usable a-c output voltage is less than the full-scale peak-to-peak level used for calibration above. *Front panel output jacks maximum is .5 v rms @ 60 cps, AUX OUTPUT terminals 3.5 v rms up to 250 cps and 2.5 v at 400 cps.

If desired, an a-c VTVM can be used along with the oscilloscope. A recorder having suitable frequency response and sensitivity can be used in place of the oscilloscope, using the same method for calibration. Unless the YA-478 or other external filter is used, a small 1.1 KC carrier ripple will appear in the output.

H. TOTAL FLUX DETERMINATION

The Hall-effect sensing device is inherently responsive to magnetic flux density and not to total flux lines. It is not dependent on rate-of-change of flux as is a search coil.

From the basic definitions:

GAUSS = WEBERS PER SQUARE METER x 10^4

GAUSS = LINES PER SQUARE INCH x .1550

The Hall probe is equally useful in homogenous, uniform low-gradient fields and in high-gradient fields. If the flux density is uniform over a given area, the total flux thru the area is found by multiplying by the area in question.

$$\text{(Flux) WEBERS} = \text{GAUSS} \times \text{SQ. METERS} \times 10^{-4}$$
$$= \text{GAUSS} \times \text{SQ. CM} \times 10^{-8}$$

$$\text{(Flux) LINES} = \frac{\text{GAUSS} \times \text{SQ. INCHES}}{.1550}$$

When the Hall device is moved in a plane, the component of flux normal to this plane will be indicated.

If the field varies in magnitude and direction over the area, it is necessary to integrate the values of flux density over the area in question. The flux density value indicated by the Hall probe output, is the effective value over the active area of the Hall element. Fortunately, Hall-Pak devices have extremely small active areas. The standard transverse BH200 device area is only .014 sq. inch. The smaller BH207 or BH201 and axial BH204 is only .0018 sq. inch. Smaller devices are available on special order from F. W. Bell, Inc. Due to variations in response over this area, as well as field curvature, the Hall device is not recommended for total flux measurements.

Absolute measurements of total flux of magnets having odd shape or high length-to-diameter ratio are best made using the search coil and ballistic galvanometer methods. In many cases, however, valuable data are obtained by air-gap flux density measurements when the magnet is mounted in its working structure. Also, accurate comparison data can be obtained on almost all magnets of various sizes and shapes using a Hall probe to measure pole face density in comparison to a magnet selected as a standard of reference. The incremental feature, as will be explained, is most valuable for this type of work.

*Except when using YA-478 400 cycle filter, see specifications.

III-6 INCREMENTAL OPERATION

A. MAKING INCREMENTAL MEASUREMENTS

Incremental operation of the Model 240 Gaussmeter is obtained by the method of "zero suppression" and "scale expansion". Zero suppression is accomplished by introducing a feedback signal generated within the Model 240 to "buck out" the signal due to the field to be measured. The FEEDBACK INCREASE switch thus introduces a reverse (downscale) meter deflection.

Scale expansion results when the sensitivity is increased by switching to lower gauss ranges. Note that the meter scale, although no longer reading absolute gauss, is still calibrated as far as changes in flux density are concerned. This is because with feedback, the meter reads the difference between the actual flux density and the constant amount due to feedback; i.e. the excess gauss over the reference signal. Thus the Model 240 is direct-reading in ΔB, or incremental gauss changes, as indicated by the range on which ΔB measurements are made.

The feedback method can be used over the range of 10 gauss or slightly less, to approximately 14 KG. Fields below 10 gauss can be read incrementally by off-set of the probe zero controls.

The rated 100 times (100 X) scale expansion is maximum for Model 240. This expansion ratio refers to the full-scale range on which the field is measured and always amounts to four steps on the range attenuator. Thus, a 5 KG field, reading ½ scale on the 10 KG range, can be expanded 1/100th of 10 KG to the 100 G incremental range. In this case resolution is 1 gauss per minor scale division, or 1 part in 5000 of the actual field value. In many cases, 100 X expansion of fields whose value falls 10 to 20% over a full-scale range is possible without an overload (as indicated by the overload light) and probe thermal effects which are multiplied by the expansion factor.

The constant feedback signal can "zero out" steady or d-c fields only. The remaining incremental signals may vary at any rate from zero to 60 cps, (400 cps if equipped with filter) in accordance with the response plot shown on the curve sheet. If the incremental signal is a slow change, it will be read on the panel meter. If it is a-c, the readout will be as described for a-c fields. Calibration obtains by use of the fact that output voltage is proportional to full scale or fractions thereof, of the range in use.

The incremental feature does not increase the absolute accuracy of gauss measurement, but it does permit ΔB incremental gauss measurements to about the same accuracy as absolute gauss. For example, with the 100 X scale expansion capabilities of the Model 240, a 1% ΔB change is magnified to a full scale meter reading. If this ΔB change is accurate to 2% of the full scale value of the change, we have a theoretical accuracy of 0.02% of the original field. With the 100 division meter scale, small field changes can be read to 1 part in 10^4.

This feature is extremely useful not only for evaluating field strength changes, or field modulation in an electromagnet, but also for field uniformity and gradient measurements of static fields. In addition, highly precision comparison measurements can be made to a standard or reference field, for example, with comparison accuracies to 1 part in 10,000 or 0.01%. Due to the high stability of the instrument, this precision can be retained as an absolute accuracy for relatively long periods of time with periodic reference to the standard. Actual time depends on

the stability of measurement conditions, temperature of the probe, line voltage, etc. For additional data on stability and accuracy refer to paragraph III-7.

B. INCREMENTAL OPERATING PROCEDURE

The calibrating procedure and probe balance adjustments described earlier must be first carried out. DO NOT CHANGE the probe zero controls (gray knobs) after this adjustment.

Place the probe in the field to be measured, using a suitable holding fixture. Rigid probe mounting is essential since the slightest motion of the sensing element relative to the field, will cause erratic readings. Set the range switch to give the highest reading on the meter.

Now suppress the zero by advancing the FEEDBACK-INCREASE switch until the meter reads approximately zero. Bring the meter to zero using the COARSE FEEDBACK knob. Too much feedback signal will result in below-zero off-scale reading. Reducing the amount of feedback will correct this - DO NOT THROW THE REVERSE SWITCH.

Next expand the scale by increasing sensitivity, rotate the range switch counter-clockwise to lower gauss ranges. Keep the meter on scale by carefully adjusting the black coarse and fine feedback controls (DO NOT TURN THE GRAY ZERO KNOBS). The maximum scale expansion to be used is 100 X or 4 steps counter-clockwise on the gauss range switch. The range switch now indicates the full-scale width of the ΔB increment, in gauss. The reference for this increment can be placed anywhere on scale by adjustment of the black feedback knobs. It is important to keep in mind that meter readings are changes in flux density rather than absolute values.

If the change in flux becomes greater than the ΔB range selected, and the meter goes off-scale, switch to a higher gauss range, or adjust the feedback to keep the meter on scale. Switching to higher incremental gauss ranges will preserve the incremental reference, while readjusting the feedback signal will shift the reference.

The OVERLOAD indicator lamp will light if too much expansion is used, or if there are excessive noise or quadrature signals overloading the amplifier. The OVERLOAD light provides a visable signal, indicating that the peak-to-peak signal in the amplifier has exceeded the maximum value for which the amplifier circuits are linear. It does not indicate any damage to parts or circuits and the light can be left on continuously without damage or malfunction. However, readings should not be taken when the red light is lighted, or if the light goes on near the point where readings are being taken since overload errors are present. To avoid errors, switch to the next higher range. Overload can occur even when the meter indicates on scale, but should not occur until a scale expansion of 100 X has been exceeded.

When incremental operation is used for field comparisons where the probe is removed from one field and placed in another for comparison, it is necessary to hold the feedback signal constant between readings. In such cases, when the probe is removed from the field, the meter will swing off-scale and the overload light will light until the probe is again placed in the field. Although meter overload protection is designed into the circuit, it is advisable in such cases to use the meter short-circuiting terminals located on the rear panel terminal strip marked METER. If a switch is connected to these terminals and arranged to close during the overload interval between readings, the meter will be prevented from going off-scale and more rapid recovery between reading will be obtained.

C. EXAMPLE OF INCREMENTAL OPERATION

1. The probe is placed in a 1 KG field (1 KG range).
2. Feedback is increased to obtain zero reading.
3. The range switch is then stepped down from 1000 to 10 gauss range (100 X expansion).
4. Feedback is adjusted for center-scale reading on the 10 gauss range. After this adjustment, the following relations apply.

Meter Reading	Incremental Gauss	Absolute Gauss
ZERO	−5.0 G	1000−5= 995 GAUSS
+ 5 GAUSS	REFERENCE	=1000 GAUSS
+10 GAUSS	+5.0 G	1000+5=1005 GAUSS

5. Increase the field from 1000 gauss to 1005 gauss (ΔB increment=+5 GAUSS).
6. The meter will indicate to full-scale, showing an increase of 5 gauss.
7. Each minor division on the 10 gauss range is 0.1 gauss. A change of 1 division is therefore a change of 0.1 gauss in a 1000 gauss field, or 1 part in 10,000 of the 1 KG field. This is a change of 0.01% and is the limit of resolution using the panel meter.

Minor fluctuations in a strong field caused by ripple, or other recurrent modulating signals, may be studied in detail by observing on external instrumentation such as a cathode-ray oscilloscope, recording oscillograph, V.T.V.M., etc. connected to the front panel output jacks, or the AUX OUTPUT terminals. These a-c components are measured without loss of the d-c or static field value.

Since the adjustment range of the black feedback knobs exceeds and overlaps the range of adjacent switch positions of the FEEDBACK INCREASE switch, it may be possible to reach a feedback null at either of two settings of the switch. In such cases either null may be used, or the best choice may be the one which will permit the maximum 100 X scale expansion without an OVERLOAD LIGHT indication.

III-7 FACTORS AFFECTING ACCURACY OF MEASUREMENT

The following data were obtained from specified component tolerances and from tests made on production units under controlled conditions. Before shipment, all Model 240 Gaussmeters and Probes undergo a stabilizing run-in and are then tested for accuracy of measurement using accurate calibration magnets. The results of these tests, substantiated by quality control inspection records, indicate that actual measurement errors, on the average, are less than the maximums indicated in the table below. In most cases where calibration, instrument and probe errors are all involved, the possibility of occurence of both + and − errors will result in some cancellation and overall error reduction.

	Limits of error Percent of F. S. (unless noted)	Comments
A. CALIBRATION ERRORS		
1. Using calibration magnet		
a) Magnet rated error	±½%	1 KG and up
b) Estimated user insertion error	±¼%	Readability and resolution
2. Using probe CAL Constant		
a) Factory determination error	±½%	Using calibration instruments
b) Estimated user insertion error	±1%	Includes panel meter tolerance. See Note 1
B. INSTRUMENT ERRORS		
1. Scale changing errors	±½ to ±¾%	Depends on ranges used. See Note 2
2. Ampl.-Demod. linearity error	±0.2%	
3. Incremental expansion errors	0 to 5%	Depends on degree of expansion See Note 3
4. Stability		See Paragraph E-1 below
C. READOUT ERRORS		
1. Using front panel output jacks and external meter		Depends on accuracy of external meter and calibration error
2. Using panel meter on 240	±¾%	Meter scale tracking. See Note 4
3. Using Aux. output and external readout	±0.3% plus	Accuracy (error) of external meter and calibration
D. PROBE ERRORS		
1. Hall Element linearity		
a) B measurement	±1% Absolute	Typical - depends on Hall Device and portion of curve used. See Note 5
b) △ B measurement	±1% to —8% at 10kg	
2. Hall Element reversibility error	±¾%	Probe calibrated in non-reverse. See Note 6
3. Hall Element stability		See Paragraph E-2 below
E. STABILITY		
1. Instrument stability — after warm-up		
a) Zero B constant temperature drift	—10 mg per hr.	approx.
b) B - measurement drift	—0.2% per hr.	% of F.S. of range in use
c) ΔB - measurement drift	—0.2% per hr.	% of B (Absolute). See Note 8
d) Zero - B temperature error	—2 mg per °C	See Note 7 mg=milligauss
e) B - measurement temperature error	+.05% per °C	
f) ΔB - measurement temperature error	—.05% per °C	% of B (Absolute). See Note 8
g) Error due to line voltage variation	±½%	for 10% line voltage change
2. Probe Stability		
a) Zero - B constant ambient temperature drift equivalent	±2 mg per min.	approx. maximum. See Note 10
b) Zero - B drift temperature coefficient equivalent	0 to ±50 mg per °C	
c) B and △ B measurement drift vs. time	nil	
d) B and △ B measurement temperature error	—.08% per °C (—40°C to +100°C)	% of B (Absolute)

NOTES:

1. Assuming probe CAL constant is inserted using the 240 panel meter. (Note 4). Also includes CAL reference voltage tolerance.
2. Range switch attenuator uses ± ¼% matched resistors, so that maximum range attenuator error is ± ½%, except when switching between 3 - 10 gauss and 300 - 1 K gauss range where it is ± ¾%.
3. Errors as a result of scale expansion are usually small until noise signals cause amplifier operation near the overload point, then increase rapidly. See Note 9.
4. Meter scale tracking error limit is ± 1%. Production meters vary from near zero error to the 1% limit.
5. This is maximum error for most standard Hall elements to 10 KG, transverse and axial. Typical response above 10KG is shown in Fig. III-4. See Note 9.
6. This error appears only on readings taken when REVERSE switch is used in REV position.
7. Temperature coefficients shown are for the range of +20 to +50° C. air ambient temperature. Data taken after warm-up for 4 hours at room temperature.
8. For incremental operation using 100 X scale expansion. See Note 9.
9. In incremental ($\triangle$ B) operation, instrument errors, with the exception of input noise, are not multiplied by the scale expansion factor. Probe stability errors, however, are expanded by the same scale expansion factor as the signal. Only high stability probes are selected for use on the Model 240. Incremental probe linearity error is also increased depending upon the slope of the probe error curve.
10. This extremely low level probe drift is caused by minute temperature gradient variations in the Hall crystal. The measurement was made with element inside protective sleeve and with protection from room air currents and other external effects. This drift corresponds approximately to a 0.02 microvolt signal (2×10^{-8} V) at the Hall terminals.

III-8 MINIMIZING MEASUREMENT ERRORS

A. SUGGESTIONS FOR OBTAINING BEST ACCURACY

1. Allow ample warm-up time for the instrument and probe to stabilize before calibration and operation.
2. Use an accurate calibration field (magnet) for calibrating the instrument. Allow calibration magnet to stabilize at ambient measurement temperature.
3. Refer to calibration magnet frequently, particularly when using the incremental feature for comparison of fields.
4. The value of the calibration field should be at or near the full scale value of the range in use. The one exception to this is given in 5 below.
5. Calibrate the unit at a value of flux density as near as possible to the unknown value to be measured, at least on the same range.
6. When using an external meter for readout to obtain greater accuracy, the use of the front panel jacks is recommended. An external resistor connected on the output jacks to reduce the voltage to a more desirable level will not alter the accuracy relative to full-scale, altho the percentage ripple may increase slightly.
7. When using the AUXILIARY OUTPUT, highest accuracy is obtained when the AUX CAL control is used at minimum (maximum counter-clockwise) setting.
8. Probe stability errors are more noticeable at the lower gauss levels where amplifier gain is a maximum. Protect the probe as much as possible from ambient temperature changes. Air drafts across the element change the rate of heat loss from the element, changing its temperature, even though there is no actual change in air temperature. In some cases special probes can be designed for particular applications by the use of thermal insulation, encapsulation and heat sinking.
9. Probe reversability errors may be determined by carefully noting the difference in reading when the probe is rotated 180° in a field and the FIELD REVERSE switch is operated.
10. When measuring at various probe temperatures, it is best to re-zero and check calibration at each temperature point after thermal equilibrium has been reached.

The curve, (at the right), Fig. III-4, represents the performance of an average YA-247 probe and Model 240 Gaussmeter above 10 KG. The output deviates from true linearity due to magnetoresistance effects and because each probe is linearized for minimum error 0 - 10 KG. Data to within better than 1% above 10 KG can be supplied for a particular probe from the factory. Return the probe (and gaussmeter if possible) to F. W. Bell, Inc. A nominal charge is made for technical labor. Special probes are available which are linearized specifically for the area from 10 KG to 30 KG. High field probe HFA-2401 and HFT-2402 axial and transverse are available with ±.5% accuracy capability 1 gauss to 30 KG and with individual calibration curve supplied. Contact F. W. Bell, Inc. for details.

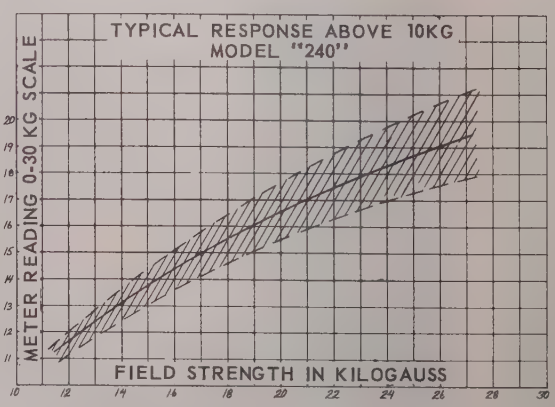


Fig. III-4 Typical Response Above 10 KG

SECTION IV
Theory of Operation

IV-1 GENERAL

The basic principle of magnetic flux measurement used in the Model 240 Gaussmeter may be described as a flux-modulated carrier-amplifier system. The Hall voltage generated in the Hall-effect sensing element is accurately proportional to flux density. A locally generated 1.1 KC a-c carrier signal, fed as an exciting current to the Hall element, causes input chopping action. The result is an a-c Hall output when the probe is placed in a static (d-c) field.

The a-c flux modulated carrier signal is amplified and then restored to d-c in the synchronous demodulator. The d-c output drives the panel meter and is available at output jacks and terminals for external use.

Incremental operation is obtained by the method of zero suppression and scale expansion. A separate input carrier signal, controlled by the feedback attenuator, and in phase opposition to the flux signal, is introduced to the input summing circuit. By careful control of phase, this feedback signal can completely cancel the flux signal, suppressing the meter zero. This permits amplifier gain to be increased up to 100 times, resulting in 100 X scale expansion. Small incremental changes in flux density are read directly on the meter. Meter scales remain direct-reading in gauss change (or incremental gauss). This is because the incremental signal is the difference between the true flux signal and a constant signal due to feedback. Expressed in gauss, it is the excess gauss over the fixed "feedback" gauss level. The high linearity of the Hall element means that the signal output-per-gauss remains constant over the usable gauss range, zero to 10 KG.

IV-2 THE SENSING ELEMENT

The Hall-Pak sensing element is a semiconductor device operating on the Hall-Effect principle. It consists of a thin rectangular wafer of high-purity indium arsenide with 4 leads attached.

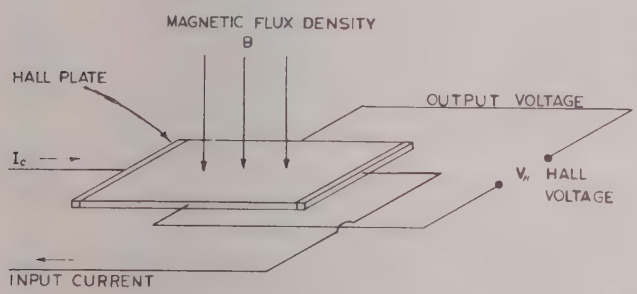


Fig. IV-1 The Hall-Effect Sensing Element

The application of control current I_C to the Hall plate results in a flow of charge carriers through the semiconductor material in the direction of its long dimension. When placed in a magnetic field the Lorenz force, acting on the moving charges, deflects them at right angles to the direction of their motion through the Hall plate. This is the same force that deflects the electron beam in a cathode-ray tube.

The resulting build-up of charge carriers along the sides of the element produces the Hall voltage, and this voltage appears at connections made on each side of the element. Hall voltage V_H is directly proportional to the flux density B and to the magnitude of control current I_C.

$$V_H = K_H B I_C$$

These three factors are mutually perpendicular. If the magnetic flux vector B is not perpendicular to the face of the Hall plate, the Hall output will be proportional to the component of B that is perpendicular to the element. The constant of proportionality K_H is called the Hall sensitivity constant, and is approximately 0.1 volt per KG - ampere, for most indium arsenide devices.

The proportionality between Hall voltage and flux density holds within 1% to 10 Kilogauss. Above 10 KG, magnetoresistance effects cause increasing departure from linearity by reducing Hall output.

IV-3 CIRCUIT OPERATION

Refer to the simplified block diagram, Fig. IV-2.

A. INPUT BALANCE NETWORK

This network, consisting of the probe zeroing controls, compensates for the ohmic unbalance inherent in the Hall device by variable external resistance connected to the Hall device terminals. These controls have sufficient range to not only compensate for zero field unbalance, but for that due to ambient steady magnetic fields up to approximately 100 gauss.

The 100 ma Hall-Pak control current, supplied by the local 1.1 KC oscillator, is fed to the probe sensing element. The balance network reduces the residual output of the element to zero. Residual reactive signals are held to extremely low levels by the non-inductive construction of the Hall-Pak, by special cable construction and by inductive balancing in the probe and gaussmeter.

In the presence of a static (d-c) magnetic field, the sensing element produces a 1.1 KC a-c output signal. The multiplying property of the Hall device provides that if the direction of the d-c field is reversed, the a-c Hall output will shift in phase by exactly 180°. When the magnetic field is alternating, and the frequency of the a-c field is low compared to the 1.1 KC carrier frequency, the Hall output is a double-side band suppressed-carrier signal. Sidebands are equally spaced about 1.1 KC by the frequency of the a-c field.

B. ATTENUATOR SECTION

The field-proportional Hall output signal is next applied to the input summing circuit. Feedback is added at this point, however, operation without feedback will first be described. As shown, the signal is next attenuated by the input RANGE attenuator according to the setting of the RANGE switch. This attenuator is a precision voltage divider connected in the grid and cathode circuits of the first cathode follower stage V1. It covers the extremely wide range of levels from .1 to 30,000 gauss with relative simplicity and accuracy.

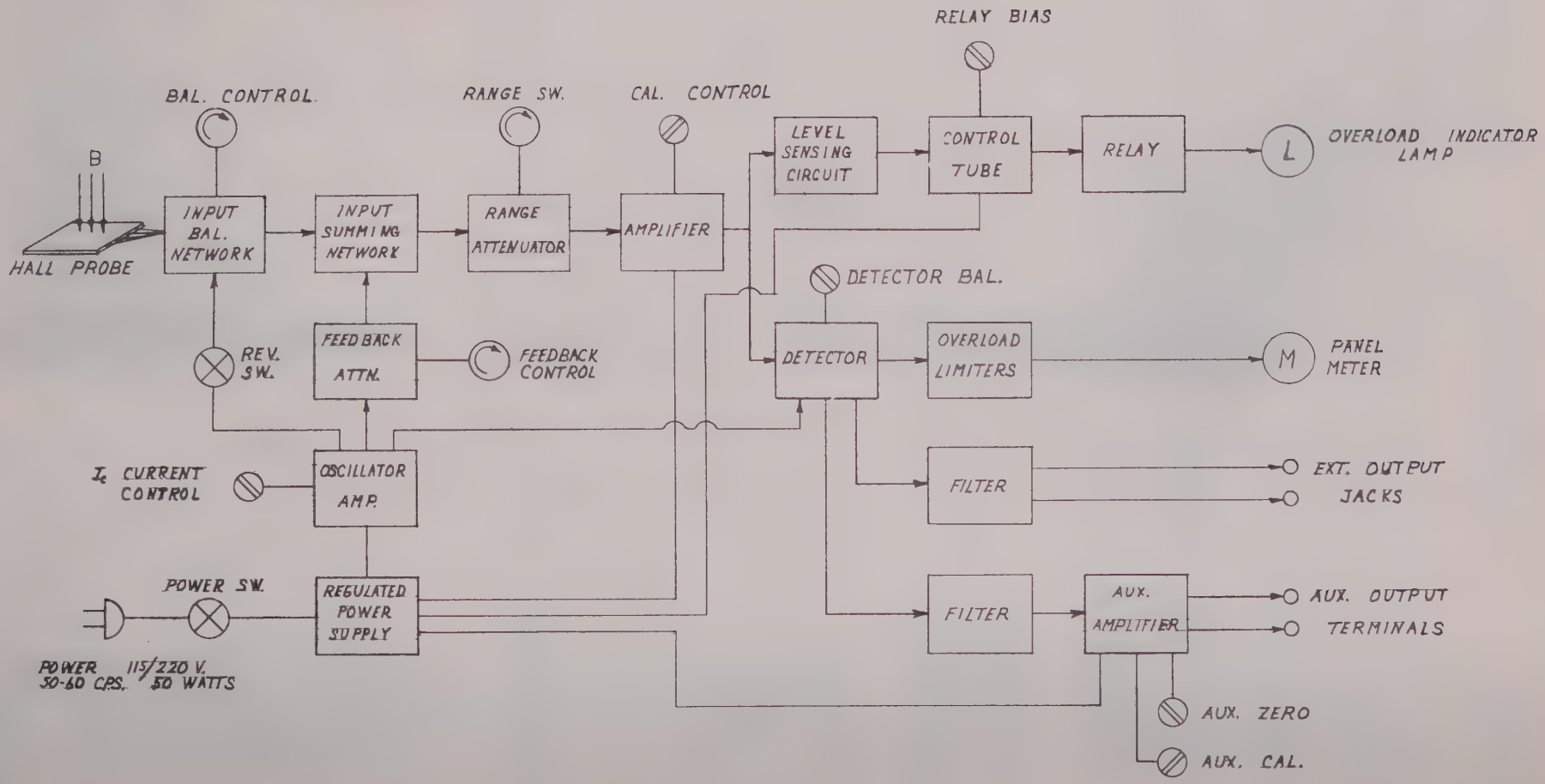


Fig. IV-2. Block Diagram, Model 240

C. AMPLIFIER-DEMODULATOR SECTION

The amplifier consists of four R-C coupled stages, two pentodes and two triodes. The last triode is a cathode follower output stage designed to feed the synchronous demodulator. The values of R and C used in the amplifier are designed to provide a band-pass frequency response centered on the 1.1 KC carrier frequency. A phase adjustment is provided since the demodulator is phase sensitive.

The synchronous demodulator is used to convert the 1.1 KC amplified Hall signal to a d-c output suitable for operating the meter and for external readout. The demodulator is a full-wave transistor switching type circuit. The transistor switches operate in phase synchronism with the 1.1 KC carrier. They operate to alternately close the circuit to ground on opposite ends of the center-tapped output transformer. Thus full-wave rectification occurs at the 1.1 KC rate, signal polarities are in synchronism with the switching polarities, and a d-c output voltage results. If the magnetic field polarity reverses, the carrier appears 180° to the switching signal, and full-wave rectification produces a d-c output of the opposite polarity. The use of a synchronous demodulator has the advantage of recovering the d-c polarity information in the output. Random noise and quadrature signals cancel, only the desired flux signal produces an output. A filter in the output of the synchronous demodulator removes the 1.1 KC carrier and its harmonics so that only the d-c output, plus the sidebands, remain.

D. AUXILIARY AMPLIFIER SECTION

An additional L-C filter is used to provide a somewhat sharper frequency cut-off for the AUXILIARY AMPLIFIER. This is a transistor d-c amplifier with a-c response in excess of the filter bandwidth. It is primarily a current amplifier with sufficient volt-ampere output capacity to operate relays or control equipment directly. Complimentary transistors are used with a large amount of overall feedback to provide maximum linearity and stability.

E. THE OVERLOAD CIRCUIT

An overvoltage sensing and indicating circuit is provided which will light the red OVERLOAD light when the amplifier peak-to-peak output signal exceeds a preset threshold level. The purpose of this circuit is to provide a warning signal to the operator when the amplifier is in overload and is no longer sufficiently linear to provide accurate output information. This is necessary since the demodulator is insensitive to noise or quandrature signals and the meter will not indicate them.

The circuit contains a pair of diodes arranged to clamp negative signal peaks to ground and to permit positive going peaks which exceed the threshold bias on the second diode, to forward bias the gas thyratron to conduction, closing the relay and turning on the red light.

F. FEEDBACK SECTION AND SUMMING CIRCUIT

A portion of the 1.1 KC oscillator output also feeds the feedback attenuator system. This consists of a step switch attenuator and continuously variable coarse and fine potentiometers. The summing circuit comprises a pair of matched, phase-balanced input transformers with series-connected secondaries. The feedback signal is introduced into the input circuit in phase opposition to the flux signal. The feedback signal therefore subtracts from the input flux signal and a downscale output results. The range of the feedback attenuator is from approximately 10 gauss to 14 KG, i.e. it will buck out a flux signal within this range. Zero suppression is obtained by introducing sufficient feedback to reduce the net signal to zero.

G. OSCILLATOR SECTION

A push-pull oscillator is used for low distortion and good amplitude stability. The buffer amplifier following the oscillator is also of balanced push-pull design and is transformer coupled to supply the Hall-Pak control current, feedback circuit current and the synchronous demodulator switching signal.

H. POWER SUPPLY

The +220 volt B+ power is supplied from a high-voltage winding on the power transformer and full-wave rectified by silicon diodes. A series regulator tube V7 is controlled by the amplified difference voltage which represents the difference between a fraction of the output voltage and the fixed reference voltage developed across reference tube V9. When the +220 v output voltage tends to rise, an error voltage appears at the grid of amplifier tube V8 which biases control tube V7 so as to reduce the error and thus hold +220 volts constant.

The power transformer also supplies +8 volts d-c and −8 volts d-c to the auxiliary amplifier. An additional winding supplies a-c anode voltage to the overload control thyratron so that it may extinguish each half-cycle of the power frequency. The d-c component of anode current operates the overload relay.

The power transformer is well shielded and has dual primaries for parallel and series connection for 117-230 volt a-c primary power. It is designed for operation on either 50 or 60 cycle current.

SECTION V
Maintenance

V-1 INTRODUCTION

This section contains the necessary instructions and diagrams for maintaining the Model 240. In addition to the schematic diagram, a block diagram giving typical signal-voltage levels is provided for rapid trouble shooting. A chassis layout diagram is also included, Fig. V-1, giving tube and control locations on the chassis.

Repair and adjustment of the instrument should be attempted in the field only where adequate test equipment and qualified personnel are available. Refer to the warranty page for the procedure to be followed should factory repair service be required.

V-2 TEST EQUIPMENT

The following test equipment is required to test and adjust the Model 240 Gaussmeter:

1. A high-impedance d-c voltmeter such as Hewlett-Packard Model 410B or 412A.
2. A high-impedance a-c voltmeter such as Hewlett-Packard Model 400D or 400H.
3. Any good oscilloscope having a response to d-c.
4. An adjustable line voltage source, accurately metered.

V-3 COVER REMOVAL

A. CAUTION

Always disconnect power cable from power line when removing or replacing the top cover.

First remove the top cover, then the bottom plate. The top cover is held in place by eight screws. After removing the screws, slide the cover forward until the clips inside the top rear strike against the front panel. Then raise the front of the cover until the cover flanges are free of the front panel. The cover will then lift off. It is easily replaced by the reverse procedure. The bottom plate is secured by six screws, three along the front and three along the rear.

V-4 PRELIMINARY PERFORMANCE TESTS

A. PRELIMINARY

1. See that all tubes are firmly seated in their correct sockets (see Chassis Layout Diagram Fig. V-1).
2. Check fuse for burn-out. Correct fuse is:
   1 amp 3 AG for 117 volt operation
   ½ amp 3 AG for 220 volt operation
3. Inspect for overheated, burned or blackened parts or wires.
4. Carefully inspect the probe for damaged element or cable, or poor plug contacts.
5. Check meter mechanical zero before turning unit on.
6. Set controls as follows before turn-on.
   RANGE switch to 30K - CAL position.
   FEEDBACK switch to OFF position.
   REVERSE switch to NORMAL position.
   CAL switch (rear panel) to normal position.
   CONTROL CURRENT switch to normal position.
7. Plug probe securely into front panel PROBE socket.

B. LINE CURRENT CHECK

1. Connect to rated power source. Line current, after warm-up should be:
   at 117 volt line .39 amp
   at 230 volt line .20 amp

C. CONTROL CURRENT TEST

1. Operate S3 CONTROL CURRENT switch to up position. The meter should indicate exactly full scale (1.0 on top scale). Adjust control R9 if necessary to bring to full scale.
2. Vary the line voltage over the range of 105 volts to 130 volts, (210 to 260 volts). Meter reading should not vary more than about ± 0.5%.
3. Restore line voltage to normal and switch to normal.

D. AMPLIFIER (CAL) TEST

1. Operate S4 CAL switch to up position. Meter should read upscale.
2. Rotate CAL control R52 over its full range. Meter reading should vary smoothly from .3 (or less on upper scale) to full scale, or beyond.
3. Adjust R52 for exactly full scale meter reading.
4. Restore S4 to normal. Meter reading should fall to zero.
5. Meter should indicate slight random noise of not more than 1 division, top meter scale.

E. OVERLOAD CIRCUIT TEST

1. Operate CAL switch S4 to up position.
2. With meter at full scale, overload light should NOT light.
3. Move RANGE switch back to 10K position, overload light should turn on immediately, meter off scale.
4. Reduce setting of R52 to just turn light off.
5. Switch range to 30K - CAL position, meter should read about .36 on top scale.
6. Reset CAL control R52 to full scale meter reading, 30K range, and return S4 to normal.

F. AUXILIARY AMPLIFIER TEST

1. Connect a d-c VTVM to AUX OUTPUT terminals on rear, common to + GND terminal. Voltage should be zero within a few millivolts.
2. Operate S4 CAL switch to up position, meter at full scale. Voltage at AUX output should be equal to voltage at front panel output jacks, i.e. −1.8 to −2.2 volt d-c. AUX CAL control should be set to minimum (full counterclockwise) for this test.
3. Rotate AUX CAL control to maximum (full clockwise). The d-c voltage should rise to −5.0 volts to −6.0 volts d-c.
4. Return AUX CAL control to minimum.
5. Throw FIELD REVERSE switch to REVERSE position. Meter should deflect downward against stop. Voltage should reverse polarity to +1.8 to +2.2 volts d-c at AUX output.
6. Return FIELD REVERSE switch to normal, S4 to normal.
7. Adjust AUX zero control R84 if necessary to bring the AUX output voltage to zero under no signal conditions where the voltage of the front panel output jacks is zero. See V-5 paragraph M.

G. FEEDBACK CIRCUIT TEST

1. Move CAL switch S4 to up position. Adjust CAL control R52 for full scale meter reading **with RANGE switch on 10KG position.**
2. Rotate FEEDBACK INCREASE switch slowly in INCREASE direction over full range. Meter should

gradually indicate downscale toward zero. At full clockwise rotation of FEEDBACK switch, meter should deflect past zero and indicate against downscale stop.

3. Return FEEDBACK switch to OFF. Reset R52 with RANGE switch in 30 KG position, then return S4 to normal.

H. PROBE BALANCE TEST

NOTE: Adjust CAL control R52 to calibrate probe for this test.

1. With probe in zero gauss chamber or shield can, reduce RANGE switch to lower positions and zero probe as described in Section III-3.
2. It should be possible to reach satisfactory balance on the .1 gauss range on standard probes.
3. The OVERLOAD light should not light on the .1G range until the meter indicates past full scale reading.
4. Zero controls should operate smoothly. If FINE ZERO control is noisy, causing erratic reading as control is rotated, it can usually be self-cleaned by rotating back and forth 8 or 10 times over full range. Noise should be barely noticeable.
5. With probe protected from air drafts, meter should indicate only slight drift on the .1G range depending on how well probe and gaussmeter are warmed up and stabilized to operating temperature. The factory limit on standard probes is about 2 milligauss (2 small divisions on top meter scale) per minute drift, on .1G range.
6. Noise on the .1G range, in terms of meter pointer vibration, should not exceed 1 small division p-p on the upper scale.

I. DETERMINATION OR RE-CHECK OF PROBE CAL CONSTANT

1. Insert probe, check control current and zero probe as described in III-3 and III-4.
2. Place probe in reference magnet or accurately known field. A reference magnet of 1KG is ideal for the purpose. Adjust the CAL control R52 to make meter indicate the value of the reference field as described in III-4.
3. Now remove the magnet, rotate RANGE switch to 30K - CAL position and operate the CAL switch S4 to the up position.
4. The meter reading on the upper scale is now equal to the probe CAL constant.

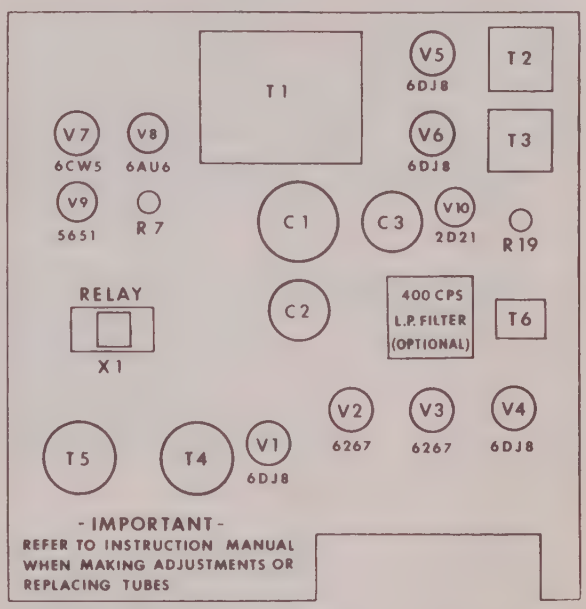


Fig. V-1. Chassis Layout Diagram (bottom view).

V-5 ADJUSTMENTS AND PERFORMANCE TESTS

Before making any adjustments the Model 240 should be turned on for at least one hour with covers in place. Line voltage should be rated value (117V or 230) unless otherwise noted.

A. METER MECHANICAL ZERO

For this test the meter terminals may be short-circuited with a jumper wire, or the instrument turned off, allowing at least 5 minutes for complete discharge of all capacitors. Read the meter accurately by aligning the pointer with its image in the mirror. Adjust the screw on the meter face to bring the pointer to exactly zero.

B. POWER SUPPLY B+ VOLTAGE ADJUSTMENT, R7

Potentiometer R7 is used to adjust the B + regulated supply voltage. The correct voltage is +220 V d-c at pin 3 V7 (6CW5). Adjust R7 to this value with the line voltage at 117 V a-c. (230 volts on units wired for this voltage). The B+ voltage should not vary more than 1 volt when the line voltage is varied from 105 to 130 V.

The d-c voltage at the output of the + 8 and — 8 volt supplies should be 7.7 to 8.3 volts with rated line voltage. The normal current output is 40 ma d-c, each supply.

C. OSCILLATOR FREQUENCY ADJUSTMENT, C7

The oscillator in the Model 240 (tube V5) is factory adjusted to oscillate at a frequency of 1100 cps ± 50 cps. If necessary, capacitor C7 may be changed to bring the frequency to the correct value. An oscilloscope, obtaining vertical signal from the center-tapped secondary (orange-white or green-white) of transformer T3, may be used for comparison to a calibrated oscillator, on the horizontal input. Make certain oscillator level is correct by adjusting R9, next paragraph.

D. CONTROL CURRENT ADJUSTMENT, R9

Adjustment R9 in V5 cathodes determines the oscillator output amplitude, thus the 1.1 KC probe control current I_C. Connect an isolated a-c VTVM across the 1 ohm ½% calibration resistor R18. Adjust R9 to obtain exactly 100 mv across R18 with rear panel S4 CAL switch in normal position. Disconnect VTVM.

E. CONTROL CURRENT METERING ADJUSTMENT, R19

Potentiometer R19 is used to adjust to full scale meter reading for 100 ma control current when S3 is operated. First make certain R9 is correctly adjusted (see paragraph D above), to give exactly 100 ma. current. Next operate S3, panel meter on 240 should read exactly full scale. If not, adjust R19 for full scale deflection. Do not make this adjustment unless the unit has been in operation for about 2 hours with covers in place.

F. DETECTOR ZERO ADJUSTMENT, R65

Connect d-c VTVM to output jacks, front panel. Remove tube V3 or connect a grounded jumper lead to pin 7 of tube V4. Switch the VTVM to a low range, (30 mv range) and adjust R65 for zero volts. Remove jumper wire or replace tube.

G. AMPLIFIER PHASE ADJUSTMENT, C28

With probe plugged in, range switch to 30K position, operate CAL switch S4 and adjust R52 CAL control for full scale deflection of the meter. Display this

signal by connecting an oscilloscope vertical input to detector test point A and horizontal input to test point B (see schematic diagram). Adjust oscilloscope for detector phase pattern, an inverted V.

Using insulated tool, adjust C28 for coincidence of the two V pattern sweeps. This test should be repeated if tube V3 is changed.

H. DETECTOR WAVE FORM, CAL SIGNAL

Connect oscilloscope d-c vertical input to detector test point A, oscilloscope sensitivity 1 volt per cm. Horizontal sweep rate 0.2msec per cm. External sync signal may be obtained from test point B. Wave form should be a full-wave rectified sine-wave, in negative direction and 3 volts amplitude for a full scale CAL signal. The d-c average value of this wave, as read on the d-c VTVM, should be 2 volts d-c ± 10%. Return S4 to normal and adjust R52 to calibrate the probe, after completing this test. Wave form errors are usually caused by circuit defects in the Q_1 - Q_2 detector circuit area.

I. DETECTOR WAVE FORM, NOISE SIGNAL

With the equipment set up described in H above, place the probe in a zero gauss chamber and zero carefully down to the 0.1 gauss range. Wave form at test point A should show only random noise and a quadrature (90° phase shifted) signal component not greater than 1½ volts peak-to-peak. A quadrature signal has a saw-tooth wave appearance since detector rectification switching occurs at the peak of the cycle of a 90° shifted sine wave. See paragraph L on shielding.

J. QUADRATURE ADJUSTMENTS

If the quadrature signal, displayed as in I above, exceeds 2.0 volts peak-to-peak, it means that:

(a) The probe quadrature adjustment (in probe handle) has been disturbed, or

(b) The probe cable has been overstressed or cable wires shifted at cable end, or

(c) The probe input socket J1 wiring adjustment has been altered or has loosened due to hard usage.

The quadrature (90° phase-shifted) signals generated in the Gaussmeter input are the result of mutual inductive coupling between the probe control current pair and the Hall output pair. These pairs are tightly twisted wires except at interconnecting tie points, and where wires are positioned and cemented to minimize quadrature. These lead placement adjustments are made at the input socket J1 rear, and inside the probe handle. Perhaps the most likely point to change would be the probe due to handling. If several probes are used, all should be checked to insure interchangeability. Extremely small changes in the position of one of the current leads with respect to one of the Hall leads will make a noticeable change in the quadrature output. Socket J1 adjustment should be changed only if a probe is used that is known to be good and correctly adjusted. See paragraph L on shielding.

K. HUM BALANCE ADJUSTMENT R57 AND LEAD DRESS

Power line (60 cycle) hum signals should be minimized even though they do not normally indicate on the panel meter. Connect an a-c VTVM to the front panel output jacks. Risiduals (hum and noise) are reduced by:

(a) Adjustment of hum balance pot R57

(b) Adjustment of lead wire loop (black-green input pair) at connections to CAL switch S4 for minimum stray induction from power transformer.

(c) Replacement of noisy and microphonic tubes

(d) Readjustment of R57 if tubes are changed.

For these tests the .1 gauss range is used, probe in zero gauss chamber and Gaussmeter carefully shielded from stray hum fields on the test bench, chassis grounded.

L. CAUTION-SHIELDING REQUIRED

When making tests or measurements with cover removed on the low gauss ranges, particularly the .1 gauss range, it is necessary to carefully shield against stray signals. Input grid V1 and grid V2 must be shielded, in particular capacitor C15. A grounded metal plate 6″ square placed over input wiring is usually sufficient.

M. AUXILIARY AMPLIFIER ZERO ADJUSTMENT, R84

This adjustment, on the rear panel, provides for zero d-c output voltage, at the AUX output terminals under zero signal conditions. Connect a jumper wire to ground the detector test point A. Connect the d-c VTVM to the AUX output terminals and adjust R84 AUX ZERO to zero output volts. The setting of AUX gain R90 will alter the zero output level slightly, and R90 should be set to the desired gain value for this test, normally at max CCW rotation (minimum gain).

N. RELAY BIAS ADJUSTMENT, R78

Potentiometer R78 determines the firing point of thyratron V10 and the signal level at which the overload relay closes. It has been adjusted and sealed before shipment from the factory and should require no further adjustment unless V10 is replaced. To adjust, obtain a test signal by operation of the CAL switch S4. Reduce R52 (CAL) to obtain full scale meter reading on the 10K range. With the d-c VTVM connected to front panel output jacks, voltage should be −2 volts ± 10%. Increase R52 to obtain an increase of .4 volt or 20% above the full scale value. At this point the relay should operate, lighting the overload light. Line voltage must be 117 volts for this adjustment. Seal the adjustment screw with cement. An oscilloscope on grid pin 1 of V10 should show only signal peaks exceeding the +4.9 volts d-c threshold bias on CR13.

O. INPUT SIGNAL PHASING ADJUSTMENT C16, INCLUDING C14, C17 and C45

The feedback signal is obtained from oscillator output transformer T3 (black-yellow pair), fed through the feedback attenuator switch S5, controls R25 (coarse) and R28 (fine) to input transformer T5 where it is added, in phase opposition, to the probe signal. The effectiveness of the feedback signal in cancelling the probe signal depends upon its being exactly 180° out of phase at all levels. When gain is increased 100 times to obtain 100 X scale expansion, phase errors are also multiplied. These appear as a quadrature signal in the amplifier output, when the meter reading (in-phase component) has been balanced to zero. They may be of sufficient magnitude, when combined with the in-phase component indicated by the panel meter, to overload the amplifier.

Phasing capacitor C16 is adjusted to minimize quadrature signals when the instrument is reading a 100 gauss field at the probe and in incremental operation with 100 X scale expansion (on the 1 gauss range). Oscilloscope wave form at the output are made under test conditions outlined in paragraph G. Capacitors C14, C17 and C45 (if used) are factory selected to minimize quadrature output over the full gauss range of the feedback system with 100 X expansion. These values should not require changing unless input transformer T4 is replaced. The peak-to-peak quadrature signal amplitude should not exceed about 2 volts except at 14 KG, 3 volts. This is with a 100 X scale expansion adjustment at each gauss level and zero meter reading.

V-6 TROUBLE SHOOTING

The following suggestions and procedure are recommended when difficulty is encountered in operating or using the instrument.

1. The probe should be checked whenever erratic operation is obtained, particularly at low levels. A fractured probe element will produce unstable and erratic operation. Check the cable also, for poor contact or wire breakage. Light finger pressure against probe element should produce only small temporary effect.
2. Excessive noise in the output is usually caused by noise developed in tube V2 if it is present on all ranges, or V1 if only on low ranges. A damaged probe element can also cause noise.
3. Make the preliminary performance tests in V-4 above, most of which can be made without auxiliary test equipment. The source of trouble should be localized in general with these tests.
4. Refer to the circuit diagram, and to the parts list, by using schematic reference symbols, to obtain detailed information on parts used. All d-c voltages are given on the circuit diagram. All signal levels and wave form information is given on the Signal Level Block Diagram (Fig. V-2).
5. Refer to paragraph V-5 for circuit adjustments and final performance tests after repairs are made.
6. It is important to replace parts with the same type and electrical value as originally used. Parts having F. W. Bell, Inc. part numbers are parts designed especially for Model 240 and should be obtained directly from the factory.
7. Use care in replacing diodes and transistors not to apply excessive heat to the leads. A heat sink is recommended, such as gripping with pliers on the lead between body of component and soldering iron.
8. Range switch S2 and Feedback Switch S5 are available from the factory as complete assemblies with all precision resistors, etc. wired in place—see parts list. Replace the complete assembly unless only a minor part is defective.
9. Do not attempt any phase adjustments without the use of an oscilloscope (Capacitor C14, C16, C17, C28, C45).
10. If necessary to return this instrument to the factory for repair, refer to SECTION VI WARRANTY.

SECTION VI

WARRANTY

F. W. BELL, INC. warrants each instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this warranty is limited to servicing or adjusting any instrument returned to our factory for that purpose, and to replacing any defective parts thereof (excluding electron tubes, batteries, transistors and probe sensing elements, which parts are covered by a standard EIA 90-day warranty). This warranty covers instruments which, within one year after delivery to the original purchaser, shall be returned with transportation charges prepaid by the original purchaser, and which upon examination shall disclose to our satisfaction to be defective. If it is determined that the defect has been caused by misuse or abnormal conditions of operation, repairs will be billed at cost after submitting an estimate to the purchaser.

F. W. BELL, INC. reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of F. W. BELL, INC., and F. W. BELL, INC. neither assumes nor authorizes any other person to assume for them any other liability in connection with the sales of F. W. BELL, INC. instruments.

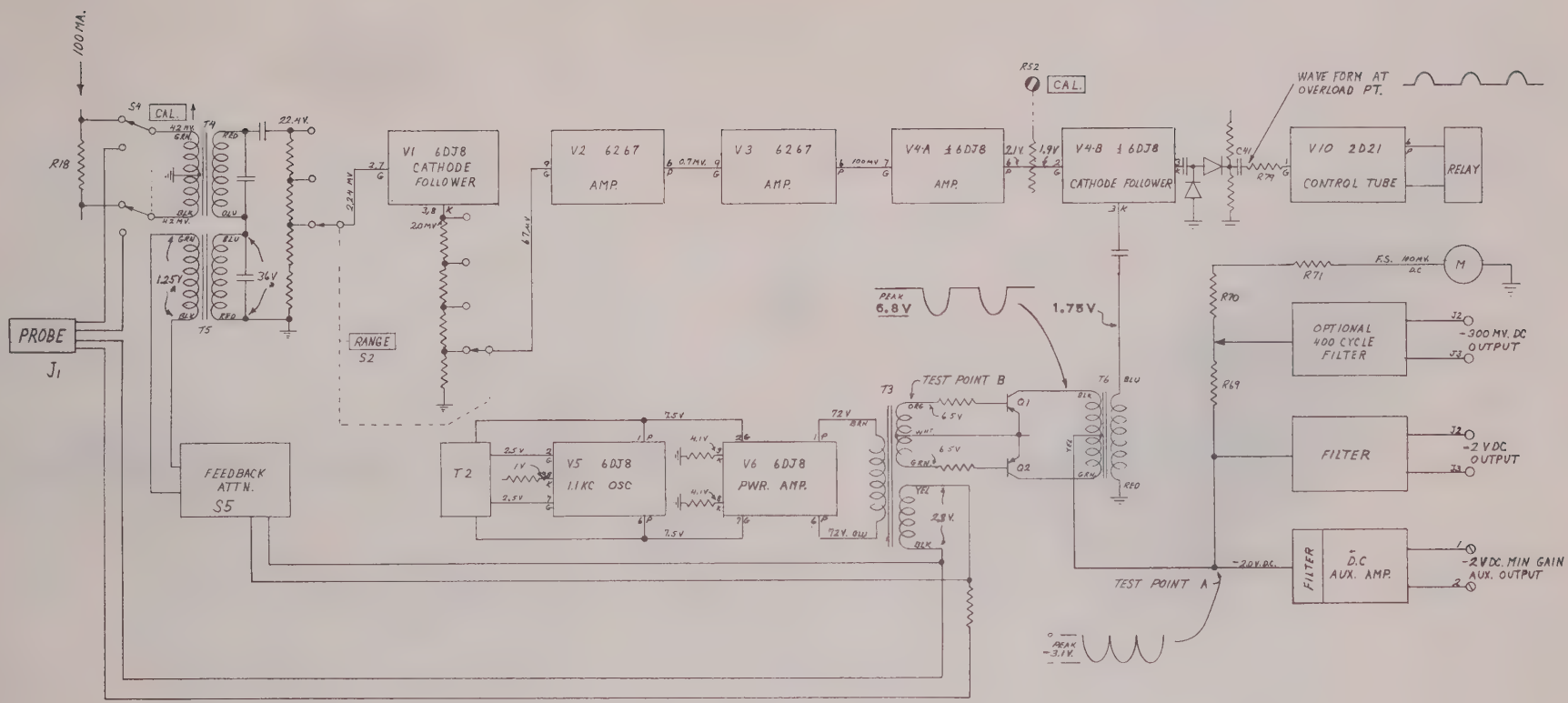
DAMAGE IN SHIPMENT

The instrument should be examined and tested as soon as it is received. If it does not operate properly, or is damaged in any way, immediately file a claim with the carrier. The claim agent will provide report forms. A copy of the completed form should be forwarded to us. We will then make the necessary arrangements for repair or replacement. All correspondence concerning this instrument should include model and serial numbers.

SHIPPING INSTRUCTIONS

All shipments of F. W. BELL, INC. instruments should be made via Railway Express or Motor Freight. Always use the original shipping carton and inserts, if possible, or pack the instrument in a sturdy container and surround the entire instrument with two or three inches of excelsior or similar shock-absorbing material.

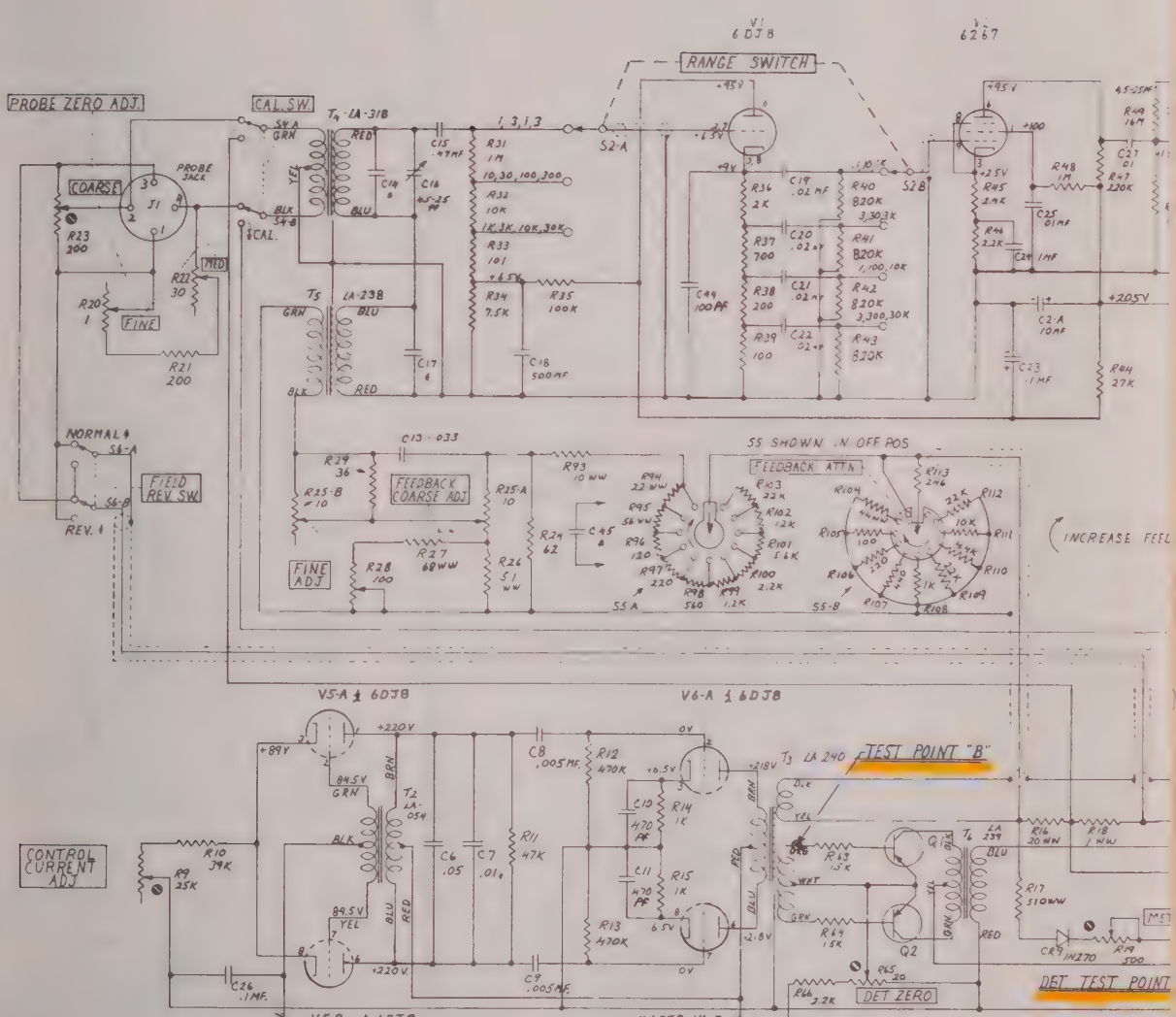
F. W. BELL, INC.
1356 NORTON AVENUE
COLUMBUS 12, OHIO
UNITED STATES OF AMERICA



NOTES:

1. CONDITIONS OF MEASUREMENT
   - A. PROBE CONNECTED.
   - B. NO OUTPUT CONNECTIONS.
   - C. CONTROL CURRENT ADJUSTED TO 100 MA.
   - D. RANGE SWITCH IN 30 K-CAL. POSITION.
   - E. S4 IN CAL. POSITION
   - F. CAL. CONTROL (R-52) ADJUSTED TO OBTAIN FULL SCALE (F.S.) METER DEFLECTION.
   - *G. FEEDBACK SWITCH (S5) IN OFF POSITION EXCEPT FOR MEASUREMENTS ON T5. (* IN MAX. FEEDBACK)
2. LETTERS AND NUMBERS OUTSIDE TUBE BLOCK INDICATE TUBE ELEMENT AND SOCKET PIN.
3. ALL VOLTAGES ARE R.M.S., 1100 C.P.S., AND MEASURED WITH RESPECT TO GROUND, UNLESS OTHERWISE NOTED.
4. AC VOLTAGES MEASURED WITH HIGH IMP. METER SUCH AS – HEWLETT-PACKARD MODEL 400D.

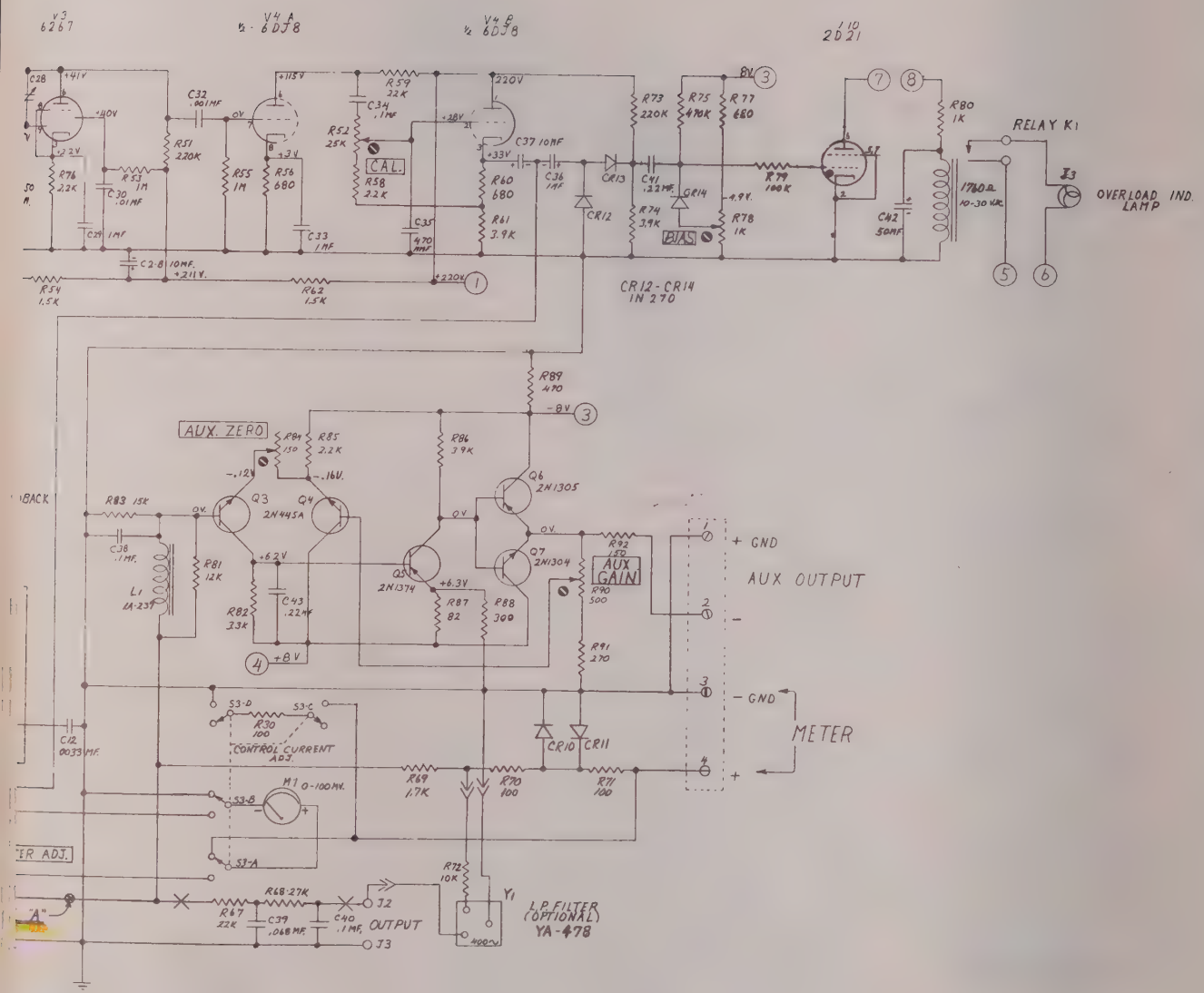
Fig. V-2. Signal Level Block Diagram, Model 240



NOTES:

1. UNLESS OTHERWISE NOTED:
   ALL RESISTANCE IN OHMS K = 1000
   ALL CAPACITANCE IN MFD.
2. *DENOTES VALUE ADJUSTED AT FACTORY FOR OPTIMUM PERFORMANCE.
3. CONDITIONS OF VOLTAGE MEASUREMENT:
   A. LINE VOLTAGE AT 117/234 V.A.C. 50/60 CPS.
   B. RANGE SWITCH IN 30K POSITION, FEEDBACK SWITCH OFF POSITION.
   C. PROBE CONNECTED.
   D. D.C. VOLTAGES MEASURED WITH RESPECT TO CHASSIS USING VTVM.

Fig. V-3. UD-656 Sch
Model 240 – Ex

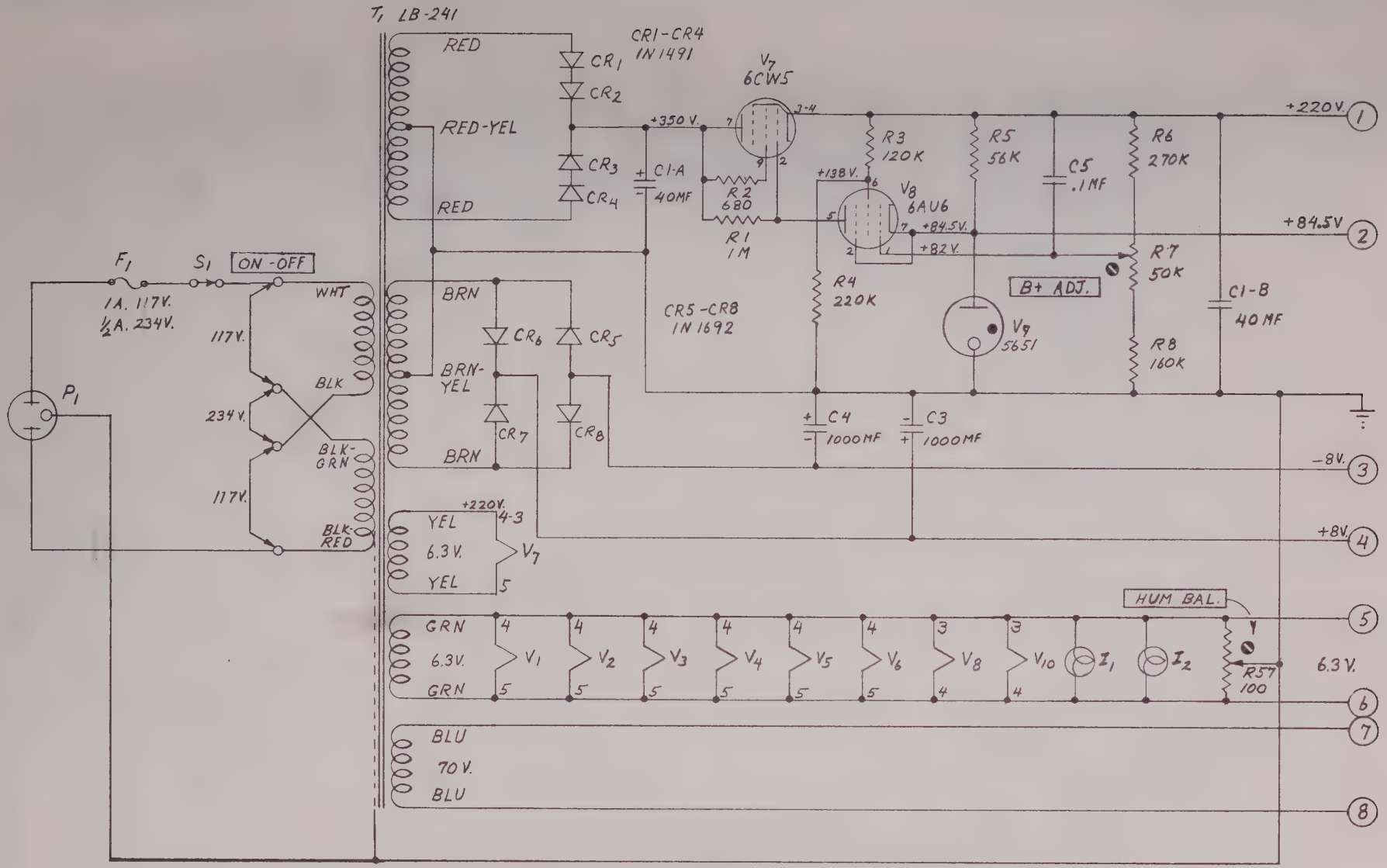


E. A.C. VOLTAGES BETWEEN POINTS IND., USING 1000 OHMS/VOLT OR HIGHER A.C. METER.

4. 400 CYCLE FILTER (OPTIONAL)
   REMOVE PARTS: R-67, 22K
   R-68, 27K
   C-39, .068MF
   C-40, .1MF
   HOOK UP AS INDICATED
   NO CONNECTION BETWEEN X & X.

5. REFER TO POWER SUPPLY DIAGRAM (UC-657) FOR CONNECTIONS TO ①, ②, etc.

ematic Circuit Diagram
cept Power Supply



NOTES:

1. FOR CIRCUIT NOTES REFER TO CIRCUIT DIAGRAM UD-656.

Fig. V-4. UC-657 Schematic Circuit Diagram
Power Supply – Model 240

SECTION VII

Parts List

Abbreviations

CER	Ceramic	MME	Miniature Mylar Epoxy Coated
Comp	Composition	MT	Mylar Tubular
DEP	Deposited Carbon	PC	Printed Circuit Board
DM	Dipped Mylar	pf	Pico Farad or 10^{-12} f (mmf)
EC	Eletrolytic, Metal Can	PMC	Paper, Metal Cased
EM	Eletrolytic, Miniature	PMT	Paper, Molded Tubular
ET	Eletrolytic, Metal Tubular	v	Working volts
f	Farad	VAR	Variable
FOP	Factory Adj. For Optimum Performance	W	Watt
		WW	Wire Wound
h	Henry	μ	Micro or 10^{-6}
K	Kilohm or 10^3 ohms	Ω	Ohm
M	Meg., Megohm or 10^6 ohms	FILM	"Metal" Film

PARTS LIST MODEL 240

Capacitors

					Bell Part Number
C1-A	40μf	450 v	EC	Fixed	
C1-B	40μf	450 v	EC	Fixed	
C2-A	10μf	300 v	EC	Fixed	
C2-B	10μf	300 v	EC	Fixed	
C3	1000μf	15 v	EC	Fixed	
C4	1000μf	15 v	ET	Fixed	
C5	.1μf	600 v	DM	Fixed	
C6	.05μf	600 v	DM	Fixed	
C7	FOP	600 v	DM	Fixed	
C8	.005μf	600 v	DM	Fixed	
C9	.005μf	600 v	DM	Fixed	
C10	470pf	1000 v	CER	Fixed	
C11	470pf	1000 v	CER	Fixed	
C12	.0033μf	600 v	DM	Fixed	
C13	.033μf	600 v	DM	Fixed	
C14	FOP	1000 v	CER	Fixed	
C15	.47μf	200 v	DM	Fixed	
C16	4.5-25pf	600 v	CER	Var.	
C17	FOP	1000 v	CER	Fixed	
C18	500μf	12 v	ET	Fixed	
C19	.02μf	200 v	DM	Fixed	
C20	.02μf	200 v	DM	Fixed	
C21	.02μf	200 v	DM	Fixed	
C22	.02μf	200 v	DM	Fixed	
C23	.1μf	600 v	DM	Fixed	
C24	1.μf	25 v	ET	Fixed	
C25	.01μf	600 v	DM	Fixed	
C27	.01μf	600 v	DM	Fixed	
C28	4.5-25pf	600 v	CER	Var.	
C29	1.μf	25 v	ET	Fixed	
C30	.01μf	600 v	DM	Fixed	
C32	.001μf	600 v	DM	Fixed	
C33	1.μf	25 v	ET	Fixed	
C34	.1μf	600 v	DM	Fixed	
C35	470pf	1000 v	CER	Fixed	
C36	1μf	25 v	ET	Fixed	
C37	10μf	100 v	ET	Fixed	
C38	.1μf	600 v	DM	Fixed	
C39	.068μf	600 v	DM	Fixed	
C40	.1μf	600 v	DM	Fixed	
C41	.22μf	200 v	PMT	Fixed	
C42	50.μf	50 v	ET	Fixed	
C43	.22μf	200 v	PMT	Fixed	
C44	100pf	1000 v	CER	Fixed	
C45	FOP	600 v	DM	Fixed	

Diodes and Rectifiers

		Bell Part Number
CR1	1N1491	
CR2	1N1491	
CR3	1N1491	
CR4	1N1491	
CR5	1N1692	
CR6	1N1692	
CR7	1N1692	
CR8	1N1692	
CR9	1N270	
CR10	66-0342 INT. RECT.	
CR11	66-0342 INT. RECT.	
CR12	1N270	
CR13	1N270	
CR14	1N270	

Fuses

F1	1 amp slo-blow MDL-1 For 117v Operation	
F1	½ amp slo-blow MDL-½ For 234v Operation	

Bulbs

I1	INCANDESCENT #47	
I2	INCANDESCENT #47	
I3	INCANDESCENT DIALCO 39-6-1471	

Jacks

J1	INPUT	YA-635
J2	OUTPUT BANANA (RED)	
J3	OUTPUT BANANA (BLACK)	

Relays

K1	MINIATURE 12 v SPDT	SA-303

Inductors

L1	Choke	LA-237

Meters

M1	0-100MV F.S.	MB-117

Transistors

Q1	2N404
Q2	2N404
Q3	2N445A
Q4	2N445A
Q5	2N1374
Q6	2N1305
Q7	2N1304

Resistors

						Bell Part Number
R1	1 Meg.	½ W	10%	Comp	Fixed	
R2	680 Ω	1 W	10%	Comp	Fixed	
R3	120 K	½ W	10%	Comp	Fixed	
R4	220 K	½ W	10%	Comp	Fixed	
R5	56 K	1 W	10%	Comp	Fixed	
R6	270 K	½ W	5%	Comp	Fixed	
R7	50 K			Comp	Var.	RA-116
R8	160 K	½ W	5%	Comp	Fixed	
R9	25 K			WW	Var.	RA-114
R10	39 K	½ W	5%	Comp	Fixed	
R11	47 K	½ W	5%	Comp	Fixed	
R12	470 K	½ W	10%	Comp	Fixed	
R13	470 K	½ W	10%	Comp	Fixed	
R14	1 K	½ W	5%	Comp	Fixed	
R15	1 K	½ W	5%	Comp	Fixed	
R16	20 Ω	3 W	3%	WW	Fixed	
R17	510 Ω	1 W	3%	WW	Fixed	
R18	1 Ω	1 W	½%	WW	Fixed	
R19	500 Ω			WW	Var.	RA-113
R20	1 Ω			WW	Var.	RA-041
R21	200 Ω	1 W	3%	WW	Fixed	
R22	30 Ω			WW	Var.	RA-042
R23	200 Ω			WW	Var.	RA-135
R24	62 Ω	½ W	5%	Comp	Fixed	
R25A	10 Ω			WW	Var.	RA-259
R25B	10 Ω			WW	Var.	RA-259
R26	5.1 Ω	1 W	2%	WW	Fixed	
R27	68 Ω	1 W	3%	WW	Fixed	
R28	100 Ω			WW	Var.	RA-095
R29	36Ω	½ W	5%	Comp	Fixed	
R30	100 Ω	½ W	5%	Comp	Fixed	
R31	1 Meg.	½ W	¼%	DEP	Fixed	
R32	10 K	½ W	¼%	WW	Fixed	
R33	101 Ω	½ W	¼%	WW	Fixed	
R34	7.5 K	½ W	5%	Comp	Fixed	
R35	100 K	½ W	5%	Comp	Fixed	
R36	2 K	½ W	¼%	WW	Fixed	
R37	700 Ω	½ W	¼%	WW	Fixed	
R38	200 Ω	½ W	¼%	WW	Fixed	
R39	100 Ω	½ W	¼%	WW	Fixed	
R40	820 K	½ W	10%	Comp	Fixed	
R41	820 K	½ W	10%	Comp	Fixed	
R42	820 K	½ W	10%	Comp	Fixed	
R43	820 K	½ W	10%	Comp	Fixed	
R44	27 K	1 W	10%	Comp	Fixed	
R45	2.4 K	½ W	5%	DEP	Fixed	
R46	2.2 K	½ W	10%	Comp	Fixed	
R47	220 K	½ W	10%	Comp	Fixed	
R48	1 Meg.	½ W	10%	Comp	Fixed	
R49	16 Meg.	½ W	5%	Comp	Fixed	
R50	1 Meg.	½ W	10%	Comp	Fixed	
R51	220 K	½ W	10%	Comp	Fixed	
R52	25 K			Comp	Var.	RA-115
R53	1 Meg.	½ W	10%	Comp	Fixed	
R54	1.5 K	½ W	10%	Comp	Fixed	
R55	1 Meg.	½ W	10%	Comp	Fixed	
R56	680 Ω	½ W	10%	Comp	Fixed	
R57	100 Ω			WW	Var.	RA-065
R58	2.2 K	½ W	10%	Comp	Fixed	
R59	22 K	1 W	10%	Comp	Fixed	
R60	680 Ω	½ W	10%	Comp	Fixed	
R61	3.9 K	1 W	10%	Comp	Fixed	
R62	1.5 K	½ W	10%	Comp	Fixed	
R63	1.5 K	½ W	5%	Comp	Fixed	
R64	1.5 K	½ W	5%	Comp	Fixed	
R65	20 Ω			WW	Var.	RA-260
R66	2.2 K	½ W	5%	Comp	Fixed	
R67	22 K	½ W	5%	Comp	Fixed	
R68	27 K	½ W	5%	Comp	Fixed	
R69	1.7 K	½ W	1%	DEP	Fixed	
R70	100 Ω	½ W	5%	Comp	Fixed	

Resistors

						Bell Part Number
R71	100 Ω	½ W	5%	Comp	Fixed	
R72	10 K	½ W	10%	Comp	Fixed	Filter Optional
R73	220 K	½ W	5%	Comp	Fixed	
R74	3.9 K	½ W	5%	Comp	Fixed	
R75	470 K	½ W	10%	Comp	Fixed	
R76	2.2 K	½ W	10%	Comp	Fixed	
R77	680 Ω	½ W	5%	Comp	Fixed	
R78	1 K			WW	Var.	RA-263
R79	100 K	½ W	5%	Comp	Fixed	
R80	1 K	½ W	5%	Comp	Fixed	
R81	12 K	½ W	5%	Comp	Fixed	
R82	3.3 K	½ W	5%	Comp	Fixed	
R83	15 K	½ W	5%	Comp	Fixed	
R84	150 Ω			WW	Var.	RA-261
R85	2.2 K	½ W	5%	Comp	Fixed	
R86	3.9 K	½ W	5%	Comp	Fixed	
R87	82 Ω	½ W	5%	Comp	Fixed	
R88	300 Ω	½ W	5%	Comp	Fixed	
R89	470 Ω	½ W	5%	Comp	Fixed	
R90	500 Ω			WW	Var.	RA-262
R91	270 Ω	½ W	5%	Comp	Fixed	
R92	150 Ω	½ W	5%	Comp	Fixed	
R93	10 Ω	1 W	1%	WW	Fixed	
R94	22 Ω	1 W	1%	WW	Fixed	
R95	56 Ω	1 W	1%	WW	Fixed	
R96	120 Ω	½ W	1%	DEP	Fixed	
R97	220 Ω	½ W	1%	DEP	Fixed	
R98	560 Ω	½ W	1%	DEP	Fixed	
R99	1.2 K	½ W	2%	DEP	Fixed	
R100	2.2 K	½ W	2%	DEP	Fixed	
R101	5.6 K	½ W	2%	DEP	Fixed	
R102	12 K	½ W	5%	DEP	Fixed	
R103	22 K	½ W	5%	DEP	Fixed	
R104	44 Ω	1 W	1%	WW	Fixed	
R105	100 Ω	½ W	1%	DEP	Fixed	
R106	220 Ω	½ W	1%	DEP	Fixed	
R107	440 Ω	½ W	1%	DEP	Fixed	
R108	1	½ W	1%	DEP	Fixed	
R109	2.2 K	½ W	2%	DEP	Fixed	
R110	4.4 K	½ W	2%	DEP	Fixed	
R111	10 K	½ W	5%	DEP	Fixed	
R112	22 K	½ W	5%	DEP	Fixed	
R113	246 Ω	½ W	1%	DEP	Fixed	

Switches

S1	Power	SPST	Toggle	
S2	Range		Rotary	SA-034
S2	Range (wired)		Rotary	YA-633
S3	Control Current Adj.	4PDT	Lever	SA-107
S4	CAL	4PDT	Lever	SA-354
S5	Feedback Attn.		Rotary	SA-242-R2
S5	Feedback Attn. (wired)		Rotary	YA-634
S6	Field Rev.	DPDT	Toggle	

Transformers

T1	Power	LB-241
T2	Osc. Drive	LA-054
T3	Osc. Output	LA-240
T4	Input (signal)	LA-318
T5	Input (feedback)	LA-238
T6	Dect. Amp. output	LA-239

Tubes

V1	6DJ8	V6	6DJ8
V2	6267	V7	6CW5
V3	6267	V8	6AU6
V4	6DJ8	V9	5651
V5	6DJ8	V10	2D21

Filters

Y1	400 CPS	L.P. Filter (optional)	YA-478

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